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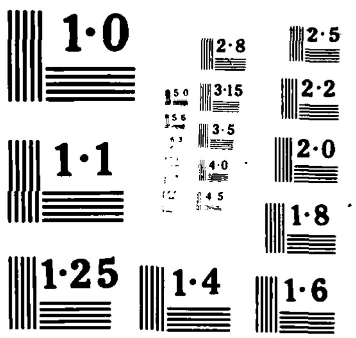
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PERCEPTION OF DEPTH WITH STEREOSCOPIC COMBAT DISPLAYS

Seaco, Inc.

Naval Ocean Systems Center San Diego, California 92152-5000

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A series of four experiments was conducted to investigate the independent and interactive effects of three video system parameters on the scaling of depth intervals viewed through stereoscopic (stereo) combat display systems. Experiment One investigated the effects of interaxial separation and lens magnification. Experiment Two investigated the effects of camera convergence. Experiments Three and Four partially replicated the video system used in Experiment One under more complex scene conditions. For all experiments, ocular fatigue induced by various combinations of system parameters was also measured. For Experiments One, Two, and Three, stereoscopic imagery produced depth interval estimates which were superior to those found under monoscopic viewing conditions. In addition, increasing camera separation and thereby increasing retinal disparities beyond "natural stereo" values improved depth interval estimation. Camera convergence exerted a significant effect with convergence in front of the area of interest providing greatest accuracy. Lens magnification was not found to exert a significant influence on depth interval estimation. No evidence of ocular fatigue was found under any conditions tested in any of the experiments.

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CONTENTS

Introduction 1

Methods 5

- Experiment One 5
- Observers 5
- Facilities and apparatus 7
- Procedures 14
- Experiment Two 20
- Experiment Three 22
- Experiment Four 25

Results 26

- Experiment One 27
- Haptic Adjustments of Perceived Depth Intervals 27
- Verbal Judgments of Perceived Depth Intervals 35
- Near-Far Test 37
- Flicker Fusion Test 40
- Questionnaire 43
- Experiment Two 49
- Haptic Adjustments of Perceived Depth Intervals 49
- Verbal Judgments of Perceived Depth Intervals 53
- Near-Far Test 59
- Flicker Test 59
- Questionnaire 62
- Experiment Three 66
- Haptic Adjustments of Perceived Depth Intervals 66
- Verbal Judgments of Perceived Depth Intervals 70
- Questionnaire 74

Discussion 85

- Experiment One 85
- Experiment Two 92
- Experiment Three 96
- Experiment Four 99

General Conclusions and Implications for Future Research 101

References 105

Appendix A 108
Appendix B 112
Appendix C 113
Appendix D 118

A-1

INTRODUCTION

A recent review of human factors affecting performance with color and stereo combat display consoles (Spain & Cole, 1983) strongly suggested that stereoscopic vision is an important aspect of remote viewing for many tasks under a wide variety of conditions. Stereoscopic vision is particularly useful under unfamiliar or degraded viewing conditions which are all too frequently encountered in field applications of remote viewing systems. Unlike the human eyes which are fixed in their sockets and have a fixed focal length optical system, stereo camera systems are easily varied in camera separation and lens magnification. Like the eyes, they can be variably converged, but the range of values within which they can be converged is much greater than that of the eyes. Consequently, there are many more possible combinations of retinal disparities, object sizes, and textural gradients under stereo TV viewing conditions than are possible under normal, everyday direct viewing conditions. The effects of camera separation, convergence angle, and magnification have all been previously studied, but always in a limited fashion. No study to date has investigated the main and interactive effects of camera separation, camera convergence angle, and image magnification on perceived depth intervals in remotely televised environments. Though there are frequent comments about increased ocular discomfort and general fatigue with stereo TV displays, no studies have objectively assessed fatigue as stereo viewing system parameters and visual information in the remote scene are systematically varied.

Designers and users of stereo imaging systems have relied heavily on purely analytical approaches or somewhat haphazard trial-and-error adjustments to configure the hardware components of stereo viewing systems. Shortcomings of both these approaches are obvious in light of the vision research literature. No single series of studies will resolve all of the uncertainties of visual perception and performance with stereo TV displays. However, the series of studies reported in this paper does provide answers to several important questions about several stereo TV parameters and thereby lays a more solid empirical foundation for configuring stereo TV systems to maximize performance while minimizing visual fatigue.

The following set of experimental hypotheses are tested in this report:

1. Increasing or decreasing camera separation relative to orthoscopic viewing conditions so that retinal disparities are enhanced or diminished produces distortions of perceived depth intervals which are in direct accordance with te geometrical model of stereopsis. Since the simple geometrical model holds that perceived depth varies directly with disparities, diminished disparities will produce underestimates of depth intervals. Conversely, exaggerated disparities will produce overestimates. The most accurate estimates will be produced by orthostereoscopic viewing conditions.

2. Magnification, like camera separation, can exaggerate or diminish disparities. When it exaggerates, depth intervals will be overestimated. Unitary magnification will produce the most accurate depth interval estimates.

3. Convergence angle affects the magnitude and polarity of disparities. Depending on its specific effects on disparities, convergence will exert an influence on depth interval estimates.

4. Non-fusable disparities in the region of patent stereopsis will provide useful depth information under stereo TV viewing conditions.

5. Including non-disparity based cues to depth and distance (i.e., interposition, textural gradients, relative height) will produce more accurate depth perception than that found under stimulus conditions in which such cues are absent.

6. The greater the deviation from orthostereoscopic viewing conditions, the greater the likelihood that eyestrain will result.

7. If present, fatigue will be differentiable between central and peripheral perceptual mechanisms on the basis of performance on tests believed to reflect the efficiency of central and peripheral mechanisms.

METHODS

Experiment One

Observers

Because of security restrictions limiting access to the testing facilities at the Naval Ocean Systems Center, only four observers were available to participate in Experiment One. Two of the observers were the author and his male laboratory assistant (ages 33 and 18). Both were highly practiced (i.e., more than 50 hours) at viewing a variety of stereo TV displays and making depth interval judgments under controlled laboratory conditions. Both served as experimenters as well as observers and were thus generally more cognizant than other observers of contingencies operating in the testing situation. Only the author was clearly aware of the experimental hypotheses being tested. Two additional observers were female clerical workers who had no exposure to stereo TV systems prior to the five one-hour practice sessions they received before commencement of Experiment One. Unfortunately, there is an obvious confoundment of observer stereo TV viewing experience and sex in this group of observers, and this eliminates the possibility of determining the independent effects of experience and sex on performance. Observers must be considered on an individual basis for theoretically interesting effects and all other effects found statistically significant for the group as a whole.

Prior to testing, five observers were screened for ocular anomalies. They were first asked questions about previous visual difficulties, recent visits to medical eye specialists, and optical corrections. Observer JR reported a history of difficulties with his left eye. According to JR, an infection of the retina encountered at age 10 left a blurry patch for central vision which has gradually healed over the past eight years. Testing revealed that he now has 20/22 (.9) Snellen acuity for the left eye. JR also has pterigium, a wing-shaped growth on the nasal sclera of both eyes which does not affect his vision but is occasionally painful. Two observers (KD and SK) wore contact lenses which corrected their eyes for myopias. All observers were administered a battery of tests of visual efficiency with a Bausch and Lomb Armed Forces Vision Tester. This battery measured stereoacuity thresholds, phorias, and Snellen acuities for near and far distances. Interpupillary distances (I_o) were measured with a Bausch & Lomb P-D gauge. Results of the visual screening procedures are summarized below in Table 1.

TABLE 1.
Results of Visual Screening Procedures

				Visual Acuity					
Obs	Sex	Age	I_o	Near Left	Near Right	Near Binoc	Far Left	Far Right	Stereo Acuity
JB*	F	>39	60	1.1	1.0	1.2	1.1	1.1	<10"
KD	F	33	60	.9	.9	1.1	.9	.9	<10"
SF	F	22	60	.9	.9	1.1	.9	.9	<10"
JR	M	18	67	.9	1.0	1.0	.9	.9	<10"
ES	M	33	67.5	1.1	1.0	1.2	1.0	1.0	<10"

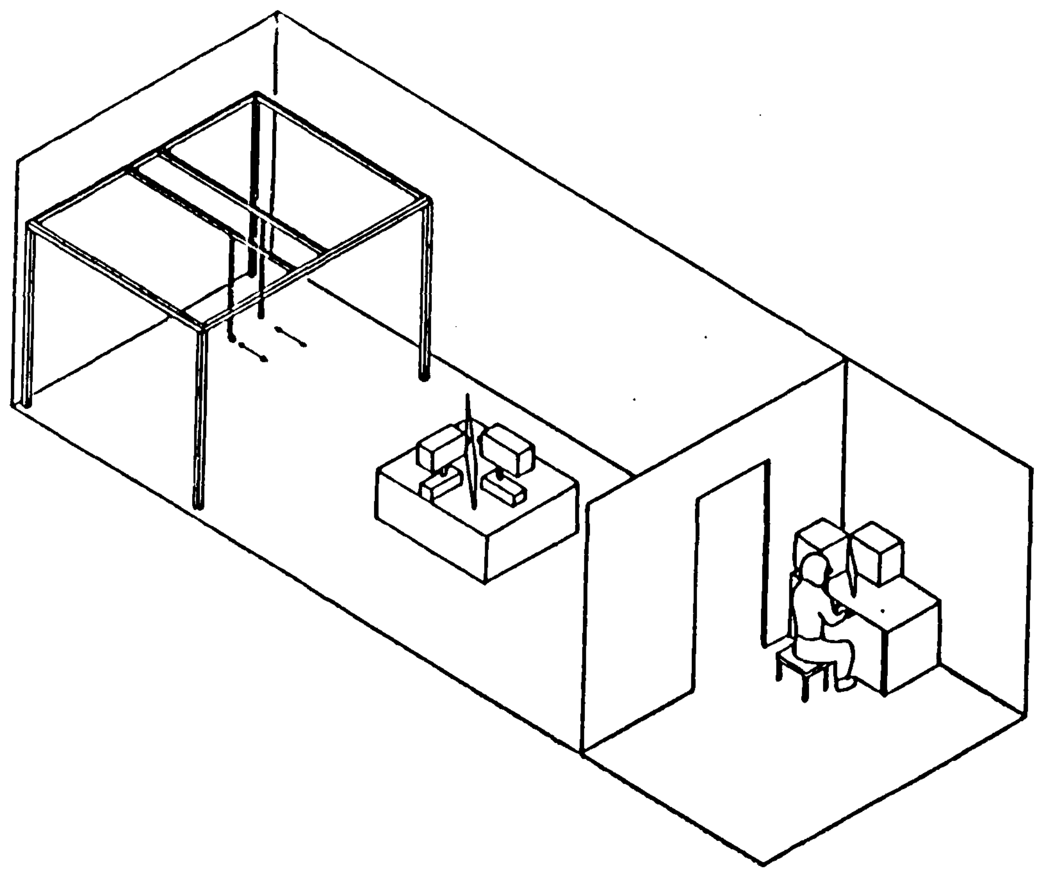
* Observer JB participated in Experiments 3 & 4 only.

Facilities and apparatus

The facility in which all experiments were conducted was the Teleoperator Performance Laboratory located at the Naval Ocean Systems Center (NOSC), Kaneohe Marine Corps Air Station, Kailua, Hawaii. This laboratory consists of a 3 meters wide by 14.5 meters long light-tight, temperature-controlled structure dedicated to visual preformance testing. It is divided into three rooms -- an 8.5 meter-long remote camera chamber, a 3 meter-long observer station, and a 3 meter-long office. Figure 1 presents a cutaway diagram of the remote camera chamber and the observer station. The remote camera station housed: 1) a microcomputer console which served as the experimenter station during the depth perception test, 2) a computer-controlled stimulus positioning apparatus, 3) the remote camera station, and 4) the Near-Far Test apparatus. The observer station contained a table-top polarizing stereo TV display and various visual screening devices. During stereo TV testing sessions the observer was isolated from the remote camera chamber and communication between the observer and the experimenter was conducted over an intercom.

Devices used in the experimentation can be organized into three distinct groups -- a stereo TV viewing system, a microcomputer controlled stimulus positioning apparatus, and devices dedicated to measuring decrements in visual performance. The central component of the control system was the Apple II+ microcomputer which was interfaced with a 12-bit

Figure 1. Testing Facility Layout .



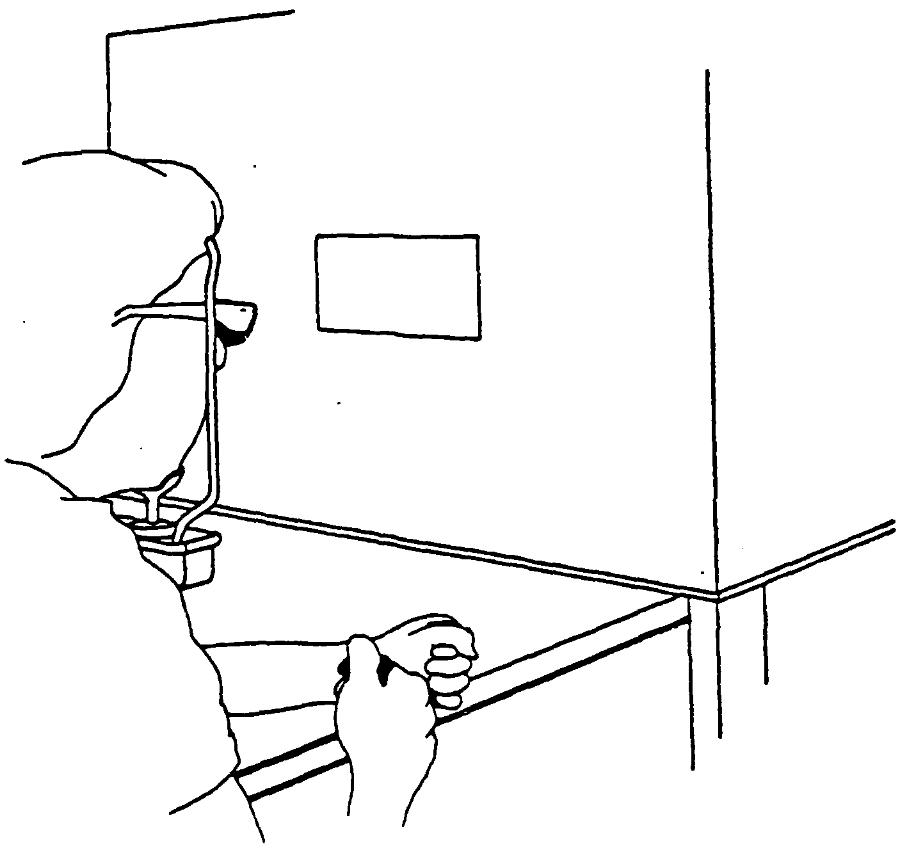
analog-to-digital converter, an Intex Talker phonemic speech synthesizer, stepper motor driving circuitry, millisecond precision timers, and four parallel 8-bit input output ports. For all experimental tests, observer's responses were collected on-line and stored to floppy disk at the conclusion of each testing session.

In order to efficiently assess the influence of specific geometrical parameters of stereo TV systems on accuracy of depth interval estimates, a versatile stereo camera bench was constructed and appears in the foreground of Figure 1. Two orthogonally positioned RCA CC002 color video cameras fitted with Canon TV (17 to 102mm) zoom lenses were optically paralleled by means of a 81 X 61 cm 70%/30% beamsplitter. A neutral density filter (.4 log unit) was placed in front of the straight view camera to equalize the beamsplitter's light filtering asymmetry. F-stops (i.e., lens apertures) for both cameras were set to 5.6 for all sessions in all experiments. The beamsplitter camera arrangement allowed camera interaxial separation between the cameras to be reduced beyond the physical limit imposed by the video camera cases. The ability to move cameras very close together made it possible to measure performance under two of the three (i.e., 3.175 cm and 19.05 cm) interaxial separations tested. For all stereo TV viewing conditions tested in Experiment One, the cameras were symmetrically converged and focused for a point 2 meters distant. Scanning signals from the video camera pair were electronically synchronized.

The stereo TV display consisted of a pair of orthogonally positioned studio-quality color TV monitors (Conrac Model SNA14/C's) which were dichoptically viewed (by means of polarized filters) through a beamsplitter which optically superimposed the two monitor's display screens. See Cole, Pepper, & Pinz (1981) for a detailed description of a similar polarizer display. The monitors' 47 cm-wide video screens were viewed from a distance of 75 cm, providing the observer with a 17.8° horizontal field of view. Observer head position and movement were controlled with a chin rest and forehead bar (see Figure 2). An adjustable chair was used to comfortably seat observers. They rested their forearms on a shelf which was attached to an apparatus consisting of two pegs used for measuring haptic depth responses. The peg on the observer's right was 2.5 cm in diameter and was not moveable. The peg on the observer's left was 1.9 cm in diameter and could be moved to various distances out to 40 cm along the observer's depth axis. It could also be pulled back toward an observer to a position 3 cm closer than the right peg. A high precision linear potentiometer was attached to the moveable peg by means of a sprocket and chain arrangement. Voltages which were attenuated by the potentiometer depending on the position of the moveable peg were input to the controlling microcomputer's analog-to-digital converter which recorded observer's haptic depth adjustments whenever a button on top of the right peg was pressed.

The stimulus positioning apparatus consisted of a 135 X 125

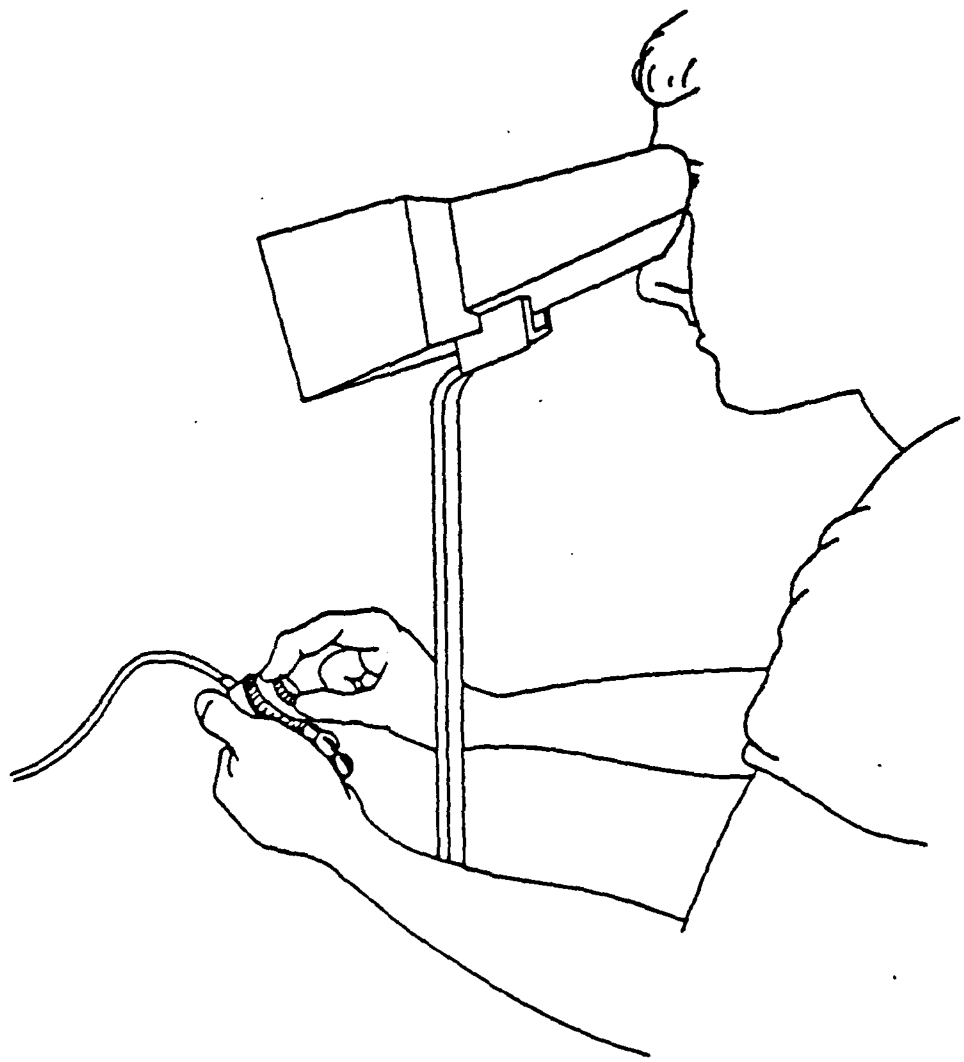
Figure 2. Stereo TV Observer Station.



cm metal beam frame to which a pair of three degree of freedom (DOF) actuators were attached. This apparatus is depicted in Figure 1. Given controlling pulses from the Apple II+ microcomputer, each of these stepper motor driven actuators was capable of precisely positioning a black 7.9 mm diameter stimulus rod anywhere within its lateral half of the total space in the metal frame. Rods were laterally separated by 12.7 cm and their movements were further restricted to a workspace centered in depth at the camera convergence point, 2 meters in front of the remote cameras. During testing, two rods were pre-positioned to one of six depth intervals (0, 5.1, 10.2, 15.2, 20.3, or 25.4 cm) within the workspace. An unpatterned white background was illuminated from above by a diffuse 1000 watt incandescent source (Berkey Colortran #104-171). This arrangement provided a bright and evenly illuminated background which did not produce shadows of the stimulus rods.

Two devices were specially constructed to measure visual fatigue resulting from use of stereo TV configurations. Both were used to measure a baseline of performance prior to testing with stereo TV and again immediately after. Shifts in pre-post performance would indicate visual fatigue. The first device consisted of two square wave pulsed light emitting diodes (LED's), a viewing hood, and a pair of lenses which allowed the observer to comfortably focus and fuse images of two LED's. The FF test observer station is depicted in Figure 3. Under computer synthesized voice instructions, the observer adjusted the setting

Figure 3. Flicker Fusion Test Observer Station.

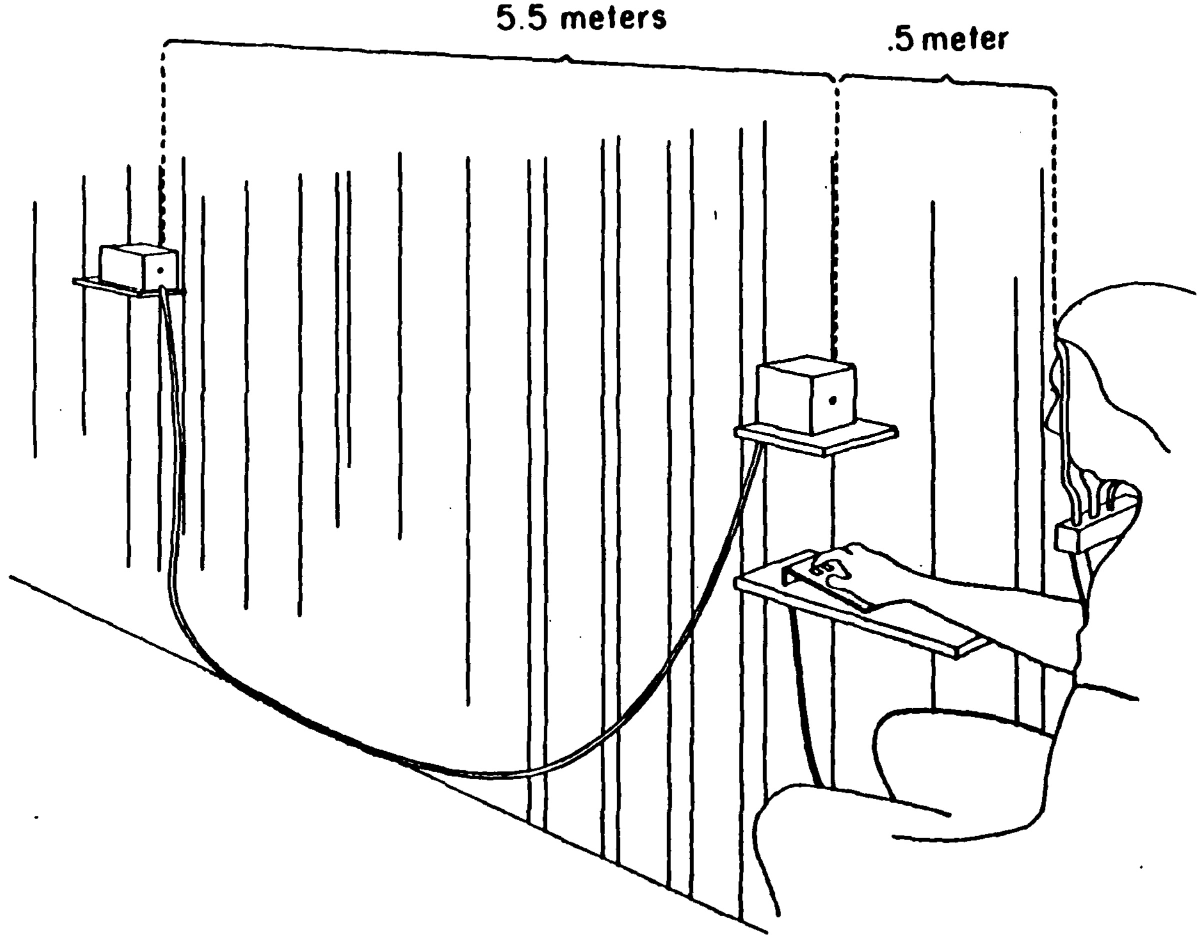


of a hand-held dial to his momentary flicker fusion threshold. The second device for measuring visual fatigue consisted of Landolt squares of equal angular subtense (1.5 arcminute gap) positioned directly in front of the observer at .5 and 6 meters (see Figure 4). Observer head position and movement were restrained with a chin rest and forehead bar. The Landolt squares were attached to stepper motors that were precisely positioned to one of four gap orientations by controlling pulses from the microcomputer. On each testing trial the observer indicated gap orientation by means of manual key presses as the near and far Landolt squares were alternately exposed to view. Response times from onset of stimulus exposure were automatically recorded to millisecond precision by the microcomputer.

Procedure

Experiment One was comprised of thirteen one-hour long testing sessions which were scheduled, whenever possible, at the same hour of the day for each observer. Each session measured performance for a single set of viewing conditions. Twelve of the sessions were derived from a full factorial crossing of four levels of camera interaxial separation (0 cm, 3.175 cm, 6.350 cm, and 19.05 cm) and three levels of image magnification (1X, 2X, and 3X). The thirteenth session was a direct view control condition in which the observer's eyes were positioned at the same location as the cameras in the 6.350 cm camera separation condition. Order of the testing sessions was randomized (see

Figure 4. Near-Far Test Observer Station.



Appendix D, Table 25) so that any practice effects between testing conditions would be minimized in the analysis.

Within a single testing session, three brief measures of visual efficiency were administered before and after measurements of perceived depth. The first of these measures was a computer-administered questionnaire (see Appendix C for text). Observers responded to eleven 5-point semantic differential scales. Five of the eleven items concerned general mood state (i.e., arousal, tension, depression, enthusiasm, concentration) while the remaining six scales were derived from a survey developed by the National Institute of Occupational Safety and Health (Smith, Cohen, & Stammerjohn, 1981) to measure visual fatigue and job stress in video display terminal operators. Scale scores on the Mood and Eyestrain components were analyzed separately in a 4 (Viewing Conditions) X 3 (Magnifications) X 2 (Pretest-Posttest) repeated measures design. After completing the questionnaire, observers were given an eight-minute rest period during which they could simply relax and adapt their eyes to the low light levels used throughout the remainder of the testing session.

Following the eight-minute rest period, the near-far test of visual acuity was administered. The text of verbal instructions for this test is included in Appendix A. Each observer received 15 practice sessions on the near-far test prior to commencement of Experiment One in order to minimize the influence of practice on results. A single test of near-far acuity was comprised of two sets of five trials each. During the first set of trials, the observer shifted convergence and accommodation from a near Landolt target (.5 meter distant) to a far Landolt target (6 meters distant). During the second set of trials, she/he shifted convergence and accommodation from the far target to the near one. The observer did this in a room that was totally dark (except for the Landolt squares, when illuminated). For each trial, an observer was required to indicate (by means of pressing one of two buttons) whether gap orientations of the near and far Landolt squares matched. Observers were counterbalanced for finger of response (middle or index finger of the right hand). Each trial began with a synthesized speech "READY" signal. One second later, the first Landolt square was illuminated. Following another one-second delay the second Landolt square was illuminated and a response time clock was started in the computer. Observers were instructed not to redirect their eyes to the second target until it was illuminated and to make their key pressing responses as quickly and accurately as possible. Incorrect responses were immediately pronounced "WRONG" by the computer's voice synthesizer. No other feedback was given to observers regarding their performance of this task. Four orders of presentation for various orientations of the target pairs were generated (see Appendix D, Table 23) and one of these orders was selected at random for each administration of the near-far test. Data was analyzed in a 4 (Viewing condition) X 3 (Magnification) X 2 (Pretest-Posttest) X 2 (Refocus Direction) repeated measures design. The entire near-far test procedure (comprised of ten trials) required approximately one minute to complete.

Immediately following the near-far test, observers were seated at the observer station and administered the flicker fusion (FF) measure. Verbal instructions for the FF measure are recorded in Appendix A. Observers viewed a pair of LED's through a stereoscope viewing hood fitted with optics which allowed them to view the pair of LED's as a single fused image at optical infinity. The LED's thus appeared to the observers as a single red circle set within a darkened surround. Observers were instructed to adjust flicker frequency to fusion threshold on four successive trials, always starting adjustments from a readily apparent 25 Hz flicker rate. They were given no feedback recording performance of this test. On two trials, the LED's flickered in counter-phase and on the remaining two trials, they flickered in-phase. Four orders of presentation for these phase relationships were generated (See Appendix D, Table 24) and one of these orders was selected at random before each administration of the FF measure. Data was analyzed in a 4 (Viewing Condition) X 3 (Magnification) X 2 (Pretest-Posttest) X 2 (Flicker Phase) repeated measures design. Each administration of the flicker fusion test required approximately 30 seconds to complete.

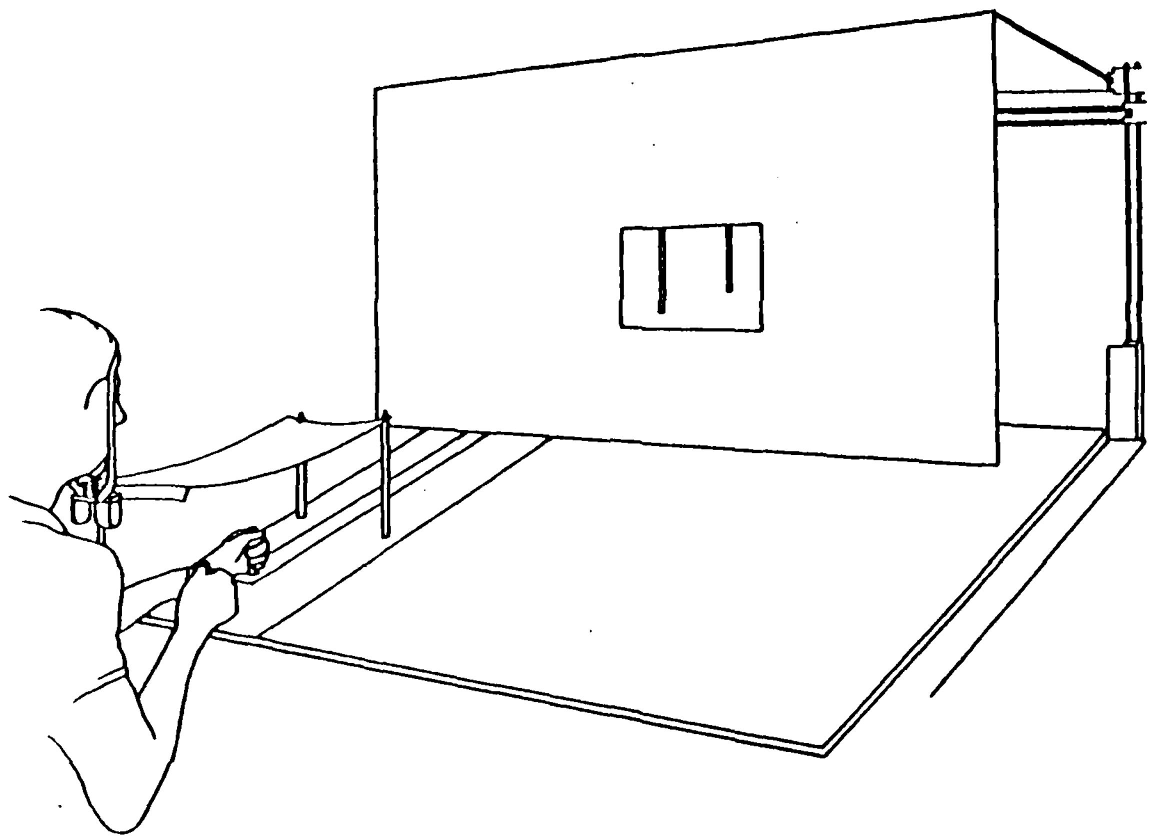
For all testing sessions (with one exception -- the direct view control condition), observers next donned a pair of polarizer eyeglasses and viewed the TV display. Each observer received no fewer than five practice sessions prior to experimental testing. Sixty trials were administered per session. Each trial began with the computer speech synthesizer announcing the trial number, blanking the video screens, and pre-positioning the stimulus rods to one of six depth intervals (0, 5.1, 10.2, 15.2, 20.3, 25.4 cm) symmetrically separated in depth around the mid-point of the workspace which was two meters directly in front of the cameras. Side of the closer rod was counterbalanced across trials for each depth interval tested so that five trials were presented for each combination of depth interval and side. Four randomized orders of presentation of depth intervals were generated (see Appendix D, Table 22) and one of these orders was selected at random for each observer at the beginning of each session. Once the rods were positioned, the video screens were turned on and the voice synthesizer asked the question "LEFT OR RIGHT?". This was the observer's prompt to verbally report the side of the rod which appeared closer in depth. The speech synthesizer then informed the observer whether his/her response was "CORRECT" or "WRONG". Next, the speech synthesizer asked the question, "HOW FAR?". This was the observer's prompt to report how far (in inches) the two rods appeared to be separated in depth. The observer received no feedback on the accuracy of her/his reply to this question. Next, the synthesizer said the word "SLIDER" which prompted the observer to adjust te depth interval between two hand-held pegs to match the perceived depth interval between the rods in the televised scene. Once she/he had done so and pressed the response button, the speech synthesizer immediately reported the direction and error of haptic adjustment in inches. Error scores for both verbal judgments of depth and haptic adjustments were analyzed separately in 4 (Viewing Conditions) X 3 (Magnifications) X 6 (Rod Depth Intervals) repeated measures designs. Total testing time for all 60 trials was on the order of 23 minutes for Experiment One. During direct view control sessions, the observer was positioned at camera depth from the rods in the remote camera chamber (see Figure 5).

Observers proceeded through the following sequence of events during a single testing session: 1) preliminary mood and eyestrain questionnaire, 2) 8 minutes of rest in a darkened room, 3) near-far acuity test, 4) flicker fusion test, 5) 60 perceived depth interval trials, 6) flicker fusion test, 7) near-far test, 8) concluding mood and eyestrain questionnaire. An entire session required approximately 50 minutes to one-hour to complete.

Experiment Two

Observers, facilities and testing procedures used in Experiment two were identical to those used in Experiment one with the following exceptions. Camera interaxial separation and lens magnification parameters which according to preliminary analysis produced the best overall performance in Experiment One (Magnification=2X Camera Separation=19.05 cm) were held constant while camera convergence angle was varied in Experiment Two. Three camera convergence settings were tested. For the first, cameras were symmetrically converged to the mid-point of the

Figure 5. Direct View Observer Station.



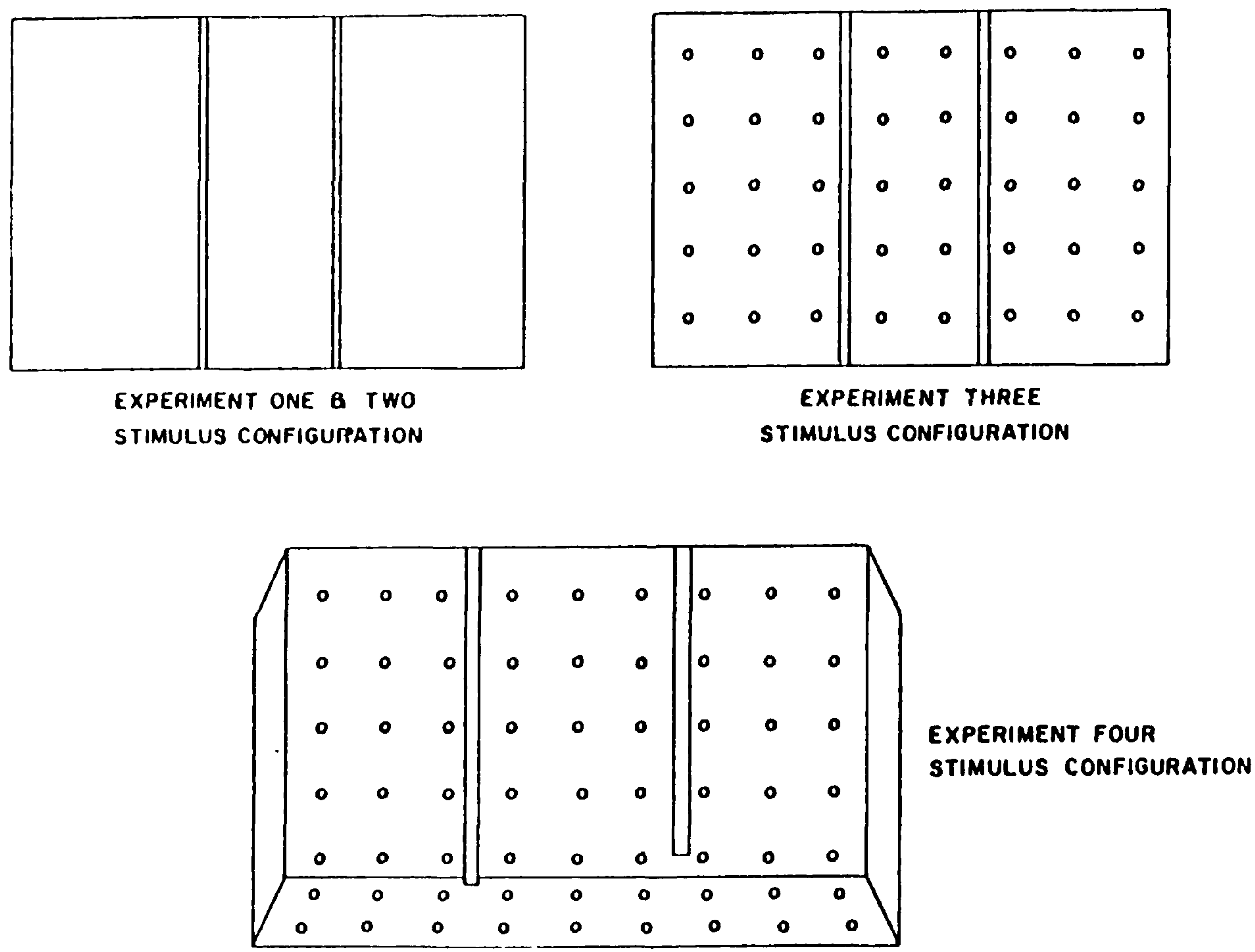
wokspace depth interval (at 2 meters) as they were throughout Experiment One. This setting produced both crossed and uncrossed screen disparities for the rods. For the second convergence condition, cameras were converged at a distance of 1.6 meters in front of the cameras. This convergence point produced only uncrossed disparities for the rods. For the third convergence condition, camera axes were paralleled and produced only crossed screen disparities for the rods. Performance under direct view and monoscopic control conditions was also measured making a total of five experimental sessions per observer. The randomized order of presentation of these testing sessions is reported in Appendix D, Table 26. Total session testing time was approximately one hour.

Experiment Three

Observers, facilities, and procedures were identical to those of Experiment Two except for the following changes. An additional observer (JB) was available to participate in Experiment Three. Visual screening procedures revealed that she had no history of problems with vision and exceptionally high visual acuity for both near and far distances (see Table 1). JB received no training sessions for stereo TV viewing prior to participating in Experiment Three. Her performance may be viewed as that of a naive observer and contrasted with performance of the four experienced stereo TV observers to assess effects of prior practice.

Since the eyestrain measures used in Experiments One and Two produced no evidence of eyestrain on either flicker fusion on near-far tests, both were eliminated from the testing protocol of Experiment Three and more trials of rod depth interval judgments were substituted in their place. As a result of this change the testing protocol for Experiment Three consisted of the following sequence of events: 1) preliminary mood and eyestrain questionnaire, 2) 96 perceived depth interval trials, and 3) the concluding mood and eyestrain questionnaire. As Figure 6 illustrates, stimulus conditions used in Experiment Three were different from those used in Experiments One and Two. Rods were presented against a regularly patterned background plane which was 62 cm behind the depth mid-point of the rod workspace (262 cm from the cameras). TV cameras were separated 19.05 cm symmetrically converged on a point 1.6 meters distant, and their lenses were set for 2X magnification. The patterned background produced uncrossed disparities at the stereo display screen. Patterning on the background plane consisted of a matrix of dots (each 1.9 cm in diameter) which were equally spaced at 12.7 cm intervals in an upright grid pattern (See Figure 6). Three camera interaxial separations were tested (3.175, 6.350, and 19.05 cm) in addition to the monoscopic and direct view control conditions. Order of sessions was randomized (see Appendix D, Table 27). Total session testing time was approximately one hour.

Figure 6. Remote Stimulus Configuration.



Experiment Four

Experiment Four was identical to Experiment Three except for the following changes. The beamsplitter camera station was tilted so that cameras were aimed down 15° off-level. Rods were presented against a clearly patterned three-dimensional background which consisted of the same dotted backplane used in Experiment Three with the addition of a similarly dotted floor plane which provided clear perspective and interposition depth cues (see Figure 6). The lower ends of the rods were clearly visible and also provided relative height cues to depth. Five testing sessions identical (except for stimulus conditions) to those used in Experiment Three were run. Randomized order of presentation for these sessions is reported in Appendix D, Table 28.

RESULTS

Experiments One through Four each produced multiple sets of visual performance measures for analysis. Scores on each measure were compiled for analysis from each testing session. Given the full factorial structure of the designs utilized in the experiments and the availability of appropriate covariate measures, it was possible to analyze each of the dependent variables with a repeated measures analysis of covariance (ANCOVA). In all cases analysis was performed with BMDP Program 2V -- analysis of variance and covariance including repeated measures (Dixon, Brown, Engleman, Frane, Hill, Jennrich, & Toporek, 1981). For each analysis, a single covariate was selected to statistically level observers on an uncontrolled factor operating in the testing situation which was previously demonstrated to be linearly related to the dependent measure. The statistical assumption of symmetry for the orthogonal polynomials in each analysis was tested with Anderson's (1958, p. 259) sphericity procedure. Whenever the symmetry hypothesis was rejected, an adjustment to the degrees of freedom of the F test (Greenhouse & Geisser, 1959; Winer, 1971, p. 523) was performed which protects for Type I errors when symmetry assumptions are violated. Analyses subsequent to ANCOVAs consisted of inspections of by observer plots for theoretically or statistically significant effects in order to determine the consistency of those effects across observers. Multiple comparisons of cell means within statistically significant effects were conducted with conservative procedures (i.e., Duncan's New Multiple Range Test reviewed in Kirk (1968), pp 93-94) which protected against Type I errors. A minimum significance criterion of $p < .05$ was set for all statistical hypotheses tested.

Experiment One

Experiment One produced six sets of dependent measures for statistical analysis, 1) haptic adjustment error scores, 2) verbal depth judgment errors, 3) near-far acuity test response times, 4) flicker fusion thresholds, 5) eyestrain questionnaire scale scores, and 6) mood state questionnaire scale scores. Data points from each of these sets of scores were collapsed across repeated trials of identical test conditions and subjected to a repeated measures analysis of covariance. The covariate used in analyses of eyestrain scores (items 1-4 above) was depth judgment testing time in minutes, while the covariate used in analyses of perceived depth measures (items 5 and 6) was observer interpupillary distance.

Haptic Adjustments of Perceived Depth Intervals

For each testing session, error scores (in inches) from 10 repeated measures for each of the six objective depth intervals were absolutized and transformed to centimeters prior to being averaged and subjected to a 4 (Viewing Condition) X 3 (Magnification) X 6 (Rod Depth Intervals) ANCOVA with observer interpupillary distance (I_o) serving as covariate. I_o was employed as a covariate in this analysis because of its simple geometrical relationship to retinal disparities. Results of this analysis are reported in Table 2.

I_o accounted for a significant proportion of variation in haptic adjustment errors ($F(1,2)=140.92$, $p=.007$) because of the very small amount of error variation associated with its effect. In my opinion, this is not likely to be due to the effect of I_o *per se*. It is more likely to be a reflection of either a sex or experience effect. Males had more experience, larger I_o's (67 and 67.5 mm), and were more accurate than the less experienced, less accurate females, both of whom had Io's of 60 mm.

Viewing condition also exerted a strong main effect ($F=72.13$, $df=(3,9)$, $p < .001$) on the results of the analysis. Cell means for this effect are plotted for each observer in Figure 7, and tests of specific cell mean differences are reported in Table 3. Although they were not included in the factorial design of the experiment, means for the direct view control condition are included in Figure 7 for comparison. Inspection of Figure 7 reveals that accuracy of haptic adjustments under stereo TV conditions was superior to that under monoscopic viewing conditions. Comparisons of cell means revealed that depth interval estimation under monoscopic and

Table 2.
Source Table of the Analysis of Covariance
for Haptic Adjustments of Depth.
Data from Experiment One.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F	TAIL PROB.
COVARIATE (I_o)	15.528	1	15.528	140.92	.007
ERROR	0.220	2	0.110		
VIEWING CONDITION (V)	103.447	3	34.482	72.13	<.001
ERROR	4.302	9	0.478		
FOV (Ω)	1.432	2	0.716	0.60	ns
ERROR	7.168	6	1.195		
V X Ω INT.	28.356	6	4.726	8.43	0.018 [g]
ERROR	10.096	18	0.561		
DEPTH (ΔR)	77.126	5	15.425	5.08	ns [g]
ERROR	45.508	15	3.034		
V X ΔR INT.	23.944	15	1.596	2.45	ns [g]
ERROR	29.342	45	0.652		
Ω X ΔR INT.	6.709	10	0.671	1.43	ns [g]
ERROR	14.036	30	0.468		
V X Ω X ΔR INT.	23.456	30	0.782	2.89	ns [g]
ERROR	23.267	90	0.271		

[g] Significance based on Greenhouse-Geisser corrected probability.

Figure 7. Viewing Condition Main Effect for Haptic Depth Adjustments. Data from Experiment One.

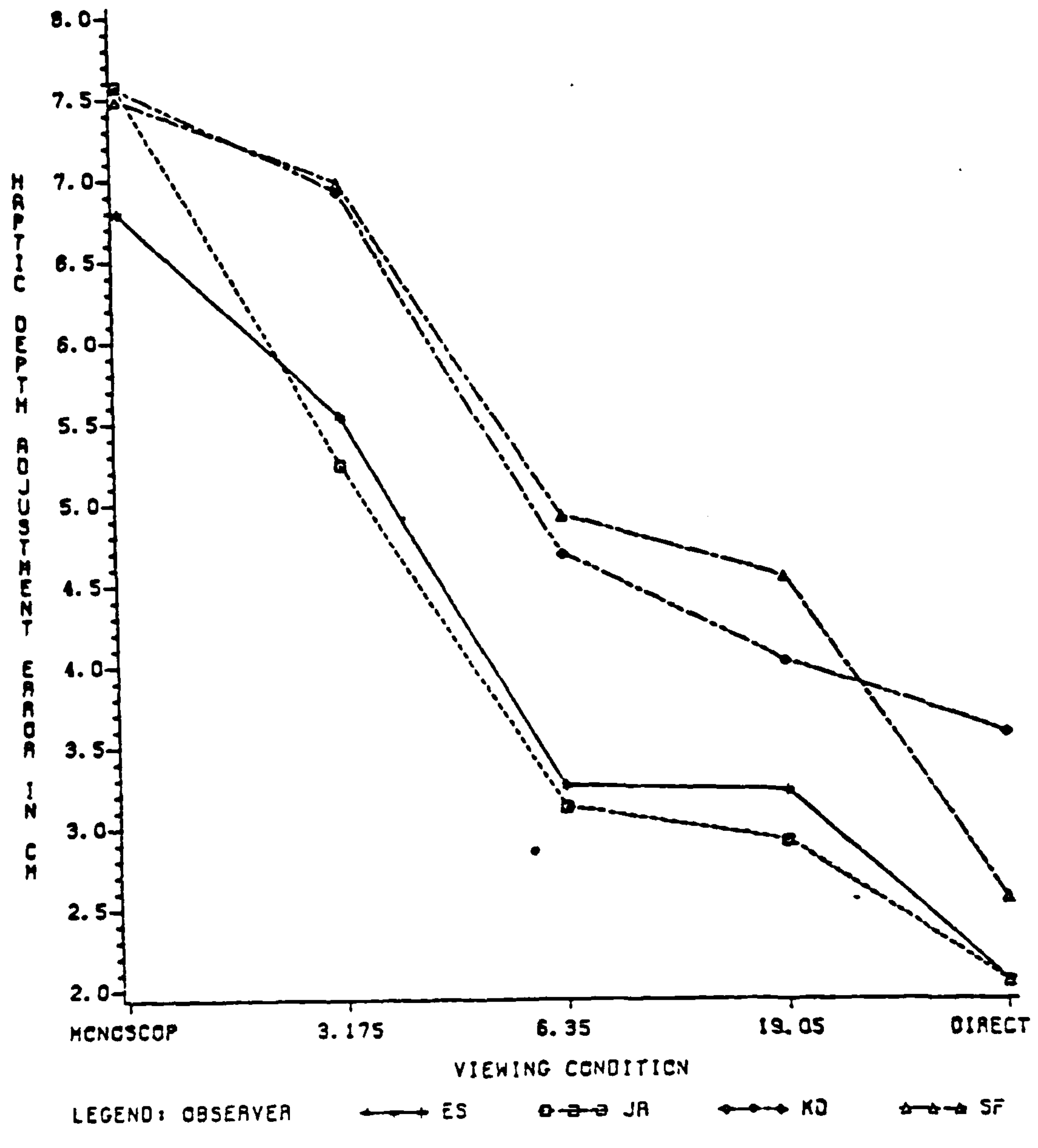


Table 3.
Duncan New Multiple Range Statistic.
Mean Scores for Haptic Adjustment Errors
on the Viewing Condition Main Effect.
Data from Experiment One.

	MONO-SCOPIC	3.175 CM	6.35 CM	19.05 CM
MEAN SCORE	7.35	6.17	3.99	3.68
MONOSCOPIC		*	**	**
3.175 CM			**	**
6.350 CM				--
19.05 CM				

* $p < .05$

** $p < .01$

reduced camera base viewing conditions (3.175 cm) was significantly poorer than estimation under orthostereoscopic (6.35 cm) and hyperstereoscopic (19.05 cm) viewing conditions. No statistically significant difference was found between orthostereoscopic and hyperstereoscopic viewing conditions. As camera interaxial separation increased, the accuracy of haptic adjustments increased. These results are consistent with previous experimental findings with stereo TV systems (i.e., Cole, Pepper, & Pinz, 1981; Pepper, Cole, & Spain, 1983; Spain & Cole, 1982) which used depth resolution as the dependent measure of depth perception. There is also a rather apparent difference in overall accuracy between more experienced male observers (JR and ES) and less experienced females (KD and SF).

A significant interaction was also found between viewing condition and camera field of view ($F(6,18)=8.43$, corrected $p=.018$). This interaction is plotted individually for each observer in Figure 8, and tests of specific cell mean differences are reported in Table 4. For both 1X and 2X magnifications, all observers showed increases in performance as camera separation increased. For the 1X and 2X magnifications, the more experienced male observers (JR and ES) showed large improvements between monoscopic and the 3.175 cm separation, and between 3.175 and 6.35 cm separations while the transition from 6.35 to 19.05 cm camera separation yielded only slight improvements in performance. The less experienced female observers (KD and SF) showed more gradual increases in performance with increases in

Figure 8. Camera Separation X Magnification Interaction for Haptic Depth Adjustments. Data from Experiment One.

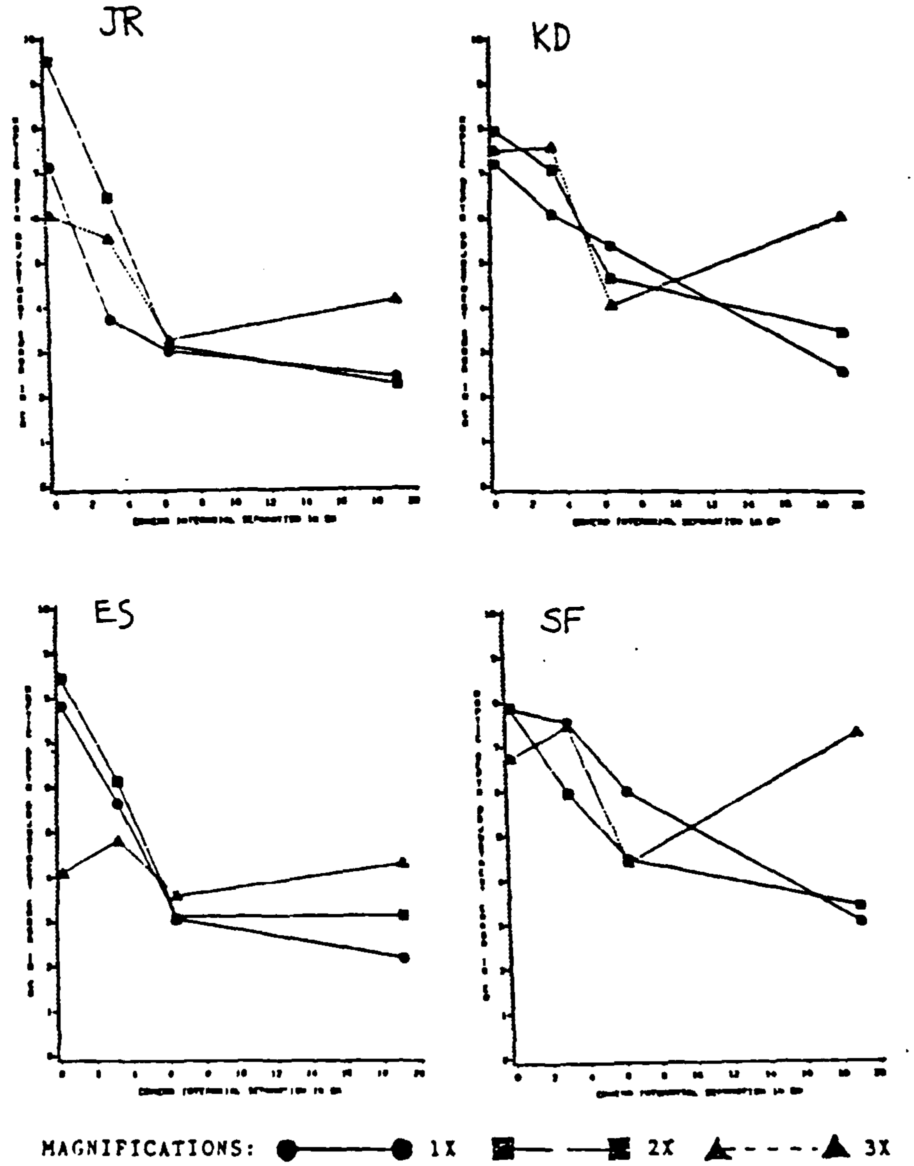


Table 4.
Duncan New Multiple Range Statistic.
Mean Scores for Haptic Adjustment Errors
on the Viewing Condition X Rod Depth Interval Interaction.
Data From Experiment One. * p < .05 ** p < .01

	Monos 1X	Monos 2X	Monos 3X	3.175 1X	3.175 2X	3.175 3X	6.35 1X	6.35 2X	6.35 3X	19.05 1X	19.05 2X	19.05 3X
MEANS	2.56	3.05	3.81	3.83	4.36	5.43	6.08	6.35	6.40	6.40	7.52	8.44
Monoscopic 1X		--	*	*	**	**	**	**	**	**	**	**
Monoscopic 2X			--	--	*	**	**	**	**	**	**	**
Monoscopic 3X				--	--	*	**	**	**	**	**	**
3.175 CM 1X					--	*	**	**	**	**	**	**
3.175 CM 2X						--	**	**	**	**	**	**
3.175 CM 3X							--	--	--	--	**	**
6.350 CM 1X								--	--	--	*	**
6.350 CM 2X									--	--	--	**
6.350 CM 3X										--	--	**
19.05 CM 1X											**	**
19.05 CM 2X												--

camera separation, with considerably greater improvement in the transition from 6.35 to 19.05 cm camera separation. The pattern of results for the 3X magnification condition was consistent for all subjects in differing from the other two magnifications. Three out of four observers showed moderate (.5 to 1 cm) decreases in haptic adjustment accuracy in the transition from monoscopic to 3.175 cm camera separations. All show moderate to substantial increases in accuracy for the transition from 3.175 cm to 6.35 cm camera separations. Under 3X magnification, all observers showed decreases in accuracy in the transition from 6.35 cm to 19.05 cm camera separation with less experienced, female observers showing larger (approximately 2 to 3 cm) decreases than the more experienced males (appoximately 1 cm). Whatever the disadvantages of using large camera separation with higher magnifications may be, they appear to be less disruptive of performance with the more highly practiced male subjects. No other statistically significant effects emerged from the analysis.

Verbal Judgments of Perceived Depth Intervals

For each testing session, error scores (in inches) from 10 repeated measures for each of the 6 rod depth intervals were absolutized and transformed to centimeters prior to being averaged and input to a 4 (Viewing Condition) X 3 (Magnification) X 6 (Rod Depth Interval) ANCOVA with observer I_o serving as the covariate. Results are reported in Table 5. The only

Table 5.
Source Table of the Analysis of Covariance
for Verbal Judgements of Depth.
Data from Experiment One.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F	TAIL PROB.
COVARIATE (I_o)	21.605	1	21.605	7.90	ns
ERROR	5.477	2	2.735		
VIEWING CONDITION (V)	58.831	3	19.610	23.63	<.001
ERROR	7.468	9	0.830		
FOV (Ω)	1.602	2	0.801	0.49	ns
ERROR	9.789	6	1.632		
V X Ω INT.	11.481	6	1.914	1.6	ns [g]
ERROR	21.488	18	1.194		
DEPTH (ΔR)	35.597	5	7.119	0.79	ns [g]
ERROR	135.318	15	9.021		
V X ΔR INT.	11.252	15	0.750	1.78	ns [g]
ERROR	18.954	45	0.421		
Ω X ΔR INT.	12.646	10	1.265	2.36	ns [g]
ERROR	16.105	30	0.537		
V X Ω X ΔR INT.	30.260	30	1.009	3.35	ns [g]
ERROR	27.096	90	0.301		

[g] Significance based on Greenhouse-Geisser corrected probability.

significant effect to emerge from the analysis was that of viewing condition ($F(3,9)=23.63$, $p < .001$). Cell means for this effect are plotted for each observer in Figure 9, and tests of specific cell mean differences are reported in Table 6. Cell means for the direct view control condition were not included in the analysis, but are plotted in Figure 9 for comparison. Stereo TV viewing conditions produced greater accuracy in depth interval estimates than monoscopic viewing conditions, although this effect was not as pronounced as the corresponding effect found for haptic adjustments. Inspection of Figure 9 suggests that experienced males produced more accurate judgments than inexperienced females. Greatest improvements in accuracy under stereo viewing conditions occurred in the transition from 3.175 to 6.35 cm camera separation. Unlike the haptic adjustments, however, there was a decrement in performance in the transition from 6.35 to 19.05 cm separations for three of the four observers. While these decrements are not large, they may suggest that "natural stereo" imagery produces more accurate perception of depth than hyperstereo does -- a suggestion which is at variance with results of the analysis of haptic adjustments.

Near-Far Test

During each experimental session, 20 NF test response times were measured -- 10 prior to making depth judgments through the TV system, 10 after. Within a single administration of the NF

Figure 9. Viewing Condition Main Effect for Verbal Depth Judgments. Data from Experiment One.

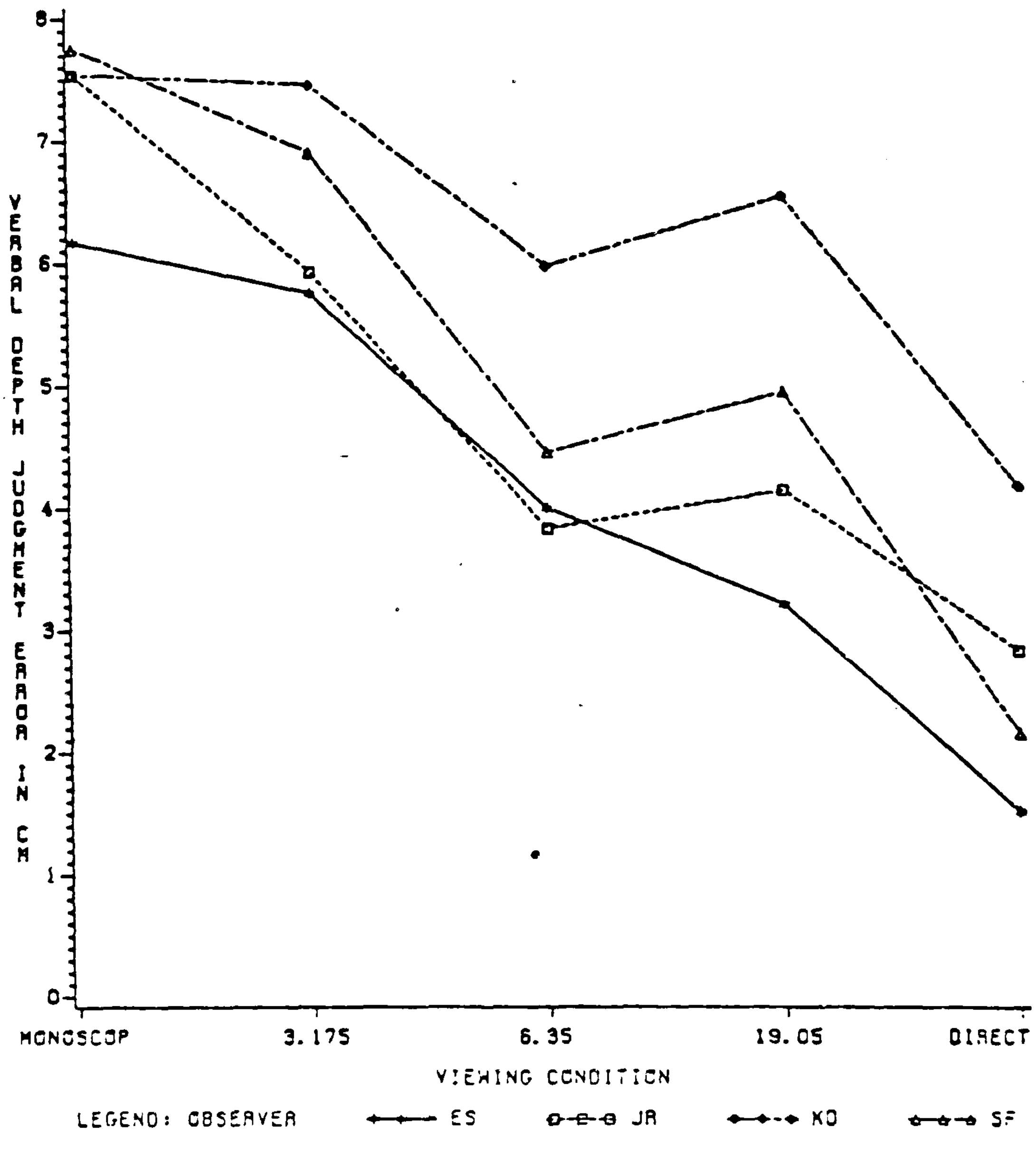


Table 6.
Duncan New Multiple Range Statistic.
Mean Scores for Verbal Judgment Errors
on the Viewing Condition Main Effect.
Data from Experiment One.

		:-- CAMERA SEPARATIONS		--:
	MONO-SCOPIC	3.175 CM	6.35 CM	19.05 CM
MEAN SCORE	7.25	6.51	4.57	4.72
MONOSCOPIC		--	**	**
3.175 CM			—	*
6.350 CM				—
19.05 CM				

* $p < .05$

** $p < .01$

test, the first five trials reflected refocus time from near-to-far distances while trials 6 through 10 reflected refocus times from far-to-near distances. Alpha reliabilities for pre-test administrations of this test were found to be .92 for near-to-far trials and .98 for far-to-near trials. Overall alpha was .97. Averaging the five measures within each of these Pretest-Posttest X Refocus Direction combinations yielded four scores per session which served as input to a 4 (Viewing Conditions) X 3 (Magnification) X 2 (Pre-Post) X 2 (Refocus Direction) ANCOVA with TV depth judgment test time as covariate. The source table for this analysis is reported in Table 7. No main or interactive effects were found for any of the factors investigated. Again, the main variable of interest was the Pre-Post contrast which would have indicated eyestrain had there been a substantial slowing of response time following TV testing. No such effects nor any interaction was found with this factor, so it must once again be concluded that substantial deviations from natural stereo TV imagery do not produce eyestrain under the testing conditions utilized in Experiment One.

Flicker Fusion Test

Each observer made eight judgments to FF threshold per session -- four prior to stereo TV trials and four after. Two in-phase and two counter-phase trials were given within a single administration of the test. Alpha reliabilities for in-phase and

Table 7.
Source Table of the Analysis of Covariance
for Near-Far Test Response Times.
Data From Experiment One.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
ELAPSED TIME (COVARIATE)	0.338	1	0.338	0.00	ns
ERROR	66.318	2	33.159		
VIEWING CONDITION (V)	0.295	3	0.983	0.26	ns
ELAPSED TIME	2.347	1	2.347	6.18	.04
ERROR	3.037	8	0.380		
FOV (Ω)	0.583	2	0.269	0.62	ns
ELAPSED TIME	0.030	1	0.030	0.07	ns
ERROR	2.167	5	0.433		
V X Ω INT.	4.520	6	0.753	1.26	ns[g]
ELAPSED TIME	0.460	1	0.460	0.77	ns
ERROR	10.138	17	0.596		
REFOCUS DIRECTION (R)	0.257	1	0.257	3.23	ns
ERROR	0.239	3	0.080		
V X R INT.	0.136	3	0.045	0.94	ns
ERROR	0.433	9	0.048		
Ω X R INT.	0.066	2	0.033	1.02	ns[g]
ERROR	0.193	6	0.032		
V X Ω X R INT.	0.738	6	0.123	1.64	ns[g]
ERROR	1.351	18	0.075		
PRETEST-POSTTEST (P)	0.252	1	0.252	0.10	ns
ERROR	12.126	3	4.042		
V X P INT.	0.371	3	0.124	1.26	ns
ERROR	0.881	9	0.098		
Ω X P INT.	0.034	2	0.017	2.00	ns
ERROR	0.051	6	0.008		
V X Ω X P INT.	1.213	6	0.202	1.56	ns[g]
ERROR	2.335	18	0.130		

Table 7.
Source Table of the Analysis of Covariance
for Near-Far Test Response Times.
Data From Experiment One.
(Continued)

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
R X P INT.	0.218	1	0.218	4.22	ns
ERROR	0.155	3	0.052		
V X R X P INT.	0.068	3	0.023	0.38	ns
ERROR	0.533	9	0.059		
Ω X R X P INT.	0.201	2	0.101	0.59	ns [8]
ERROR	1.016	6	0.170		
V X Ω X R X P	1.296	6	0.216	3.20	ns [8]
ERROR	1.217	18	0.068		

[8] Significance based on Greenhouse-Geisser corrected probability.

counter-phase flicker trials were Overall alpha was .95. Averaging the two measures within each of the Pre-Post X Flicker Phase combinations tested yielded four scores per session for analysis. Scores from 12 sessions were subjected to a 4 (Viewing Condition) X 3 (Magnification) X 2 (Pre-Post) X 2 (Flicker Phase) ANCOVA with stereo TV test time as covariate. The source table for the analysis is found in Table 8. Again, no main or interactive effects were found for any of the factors included in the analysis. Once again, the hypothesis that no changes in eyestrain resulted from various combinations of viewing conditions utilized in this environment could not be rejected.

Questionnaire

The preliminary and concluding questionnaires were divided into mood and eyestrain scales for analysis. The mood scale was composed of screen frames 1 through 5; whereas, the eyestrain scale was composed of items 6 through 11 (see Appendix C). Since polarity of two of the mood items (i.e., screen frames 2 and 6) and three of the eyestrain items (i.e., screen frames 6, 8, and 10) was reversed during administration, these items were positively rescaled prior to summing with responses on the remaining items to yield the scale scores which were analyzed. Higher scores on the mood scale indicated that the observer was more comfortable and more motivated. Higher scores on the eyestrain scale indicated an absence of common eyestrain symptoms. Since mood and eyestrain scales employed in Experiment

Table 8.
Source Table of the Analysis of Covariance
for Flicker Fusion Thresholds.
Data From Experiment One.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
ELAPSED TIME	112.317	1	112.317	1.31	ns
ERROR	171.054	2	85.527		
VIEWING CONDITION (V)	11.949	3	3.983	0.56	ns
ELAPSED TIME	2.197	1	2.197	0.31	ns
ERROR	56.878	8	7.110		
FOV (Ω)	8.096	2	4.048	3.76	ns
ELAPSED TIME	0.406	1	0.406	0.38	ns
ERROR	5.379	5	1.076		
V X Ω INT.	4.209	6	0.702	0.21	ns [g]
ELAPSED TIME	7.870	1	7.870	2.37	ns
ERROR	56.500	17	3.324		
PRETEST-POSTTEST (PP)	0.943	1	0.943	0.08	ns
ERROR	35.303	3	11.767		
V X PP INT.	2.143	3	0.714	0.39	ns
ERROR	16.615	9	1.846		
Ω X PP INT.	1.458	2	0.729	0.09	ns
ERROR	47.468	6	7.911		
V X Ω X PP INT.	18.259	6	3.043	1.34	ns [g]
ERROR	40.955	18	2.275		
PHASE (PH)	0.252	1	0.252	0.10	ns
ERROR	7.666	3	2.555		
V X PH INT.	3.772	3	1.257	0.71	ns [g]
ERROR	15.853	9	1.762		
Ω X PH INT.	9.141	2	4.571	1.56	ns
ERROR	17.523	6	2.921		
V X Ω X PH INT	20.484	6	3.414	0.60	ns [g]
ERROR	102.173	18	5.676		
PP X PH INT.	1.283	1	1.283	1.70	ns
ERROR	2.262	3	0.754		

Table 8.
Source Table of the Analysis of Covariance
for Flicker Fusion Thresholds.
Data From Experiment One.
(Continued)

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
V X PP X PH INT	10.543	3	3.514	1.38	ns
ERROR	22.921	9	2.547		
Ω X PP X PH INT	4.109	2	2.054	2.57	ns
ERROR	4.796	6	0.799		
V X Ω X PP X PH	8.682	6	1.447	0.97	ns
ERROR	26.731	18	1.485		

[g] Significance based on Greenhouse-Geisser corrected probabilities.

One were newly constructed, alpha reliabilities were calculated to determine the internal consistency of scores on the pre-test administrations across all 13 testing sessions. Alpha was found to be .98 for the mood scale and .43 for the eyestrain scale. Scores from mood and eyestrain scales were subjected to a 4 (Viewing Condition) X 3 (Magnification) X 2 (Pretest-Posttest) ANCOVA with depth judgment test time as the single covariate in both analyses. The factor of greatest interest in both ANCOVAs, the pretest-posttest contrast would interact with viewing conditions or magnification should the various levels of these factors exert differential effects on mood and eyestrain.

ANCOVA source tables for mood and eyestrain scale scores are reported in Tables 9 and 10, respectively. No main or interactive effects were found to be significant in either analysis. On the basis of these results the null hypothesis that test conditions would not influence reports of mood and eyestrain could not be rejected. More importantly, no evidence was found to support the hypothesis that variations in camera interaxial separation or lens magnification exerted differential effects on observer mood and eyestrain.

In addition, no support was found for the hypothesis that substantial variation in camera interaxial separation or lens magnification exerted substantial effects on observer mood and eyestrain.

Table 9.
Source Table of the Analysis of Covariance
for Eyestrain Scale Scores.
Data From Experiment One.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
COVARIATE (ELAPSED TIME)	0.981	1	0.981	0.04	ns
ERROR	48.852	2	24.426		
VIEWING CONDITION (V)	16.450	3	5.483	0.65	ns
COVARIATE	3.041	1	3.041	0.36	ns
ERROR	67.709	8	8.464		
FOV (Ω)	7.475	2	3.738	0.81	ns
COVARIATE	0.773	1	0.773	0.17	ns
ERROR	23.143	5	4.629		
V X Ω INT.	35.605	6	5.934	1.31	ns [a]
COVARIATE	2.476	1	2.476	0.55	ns
ERROR	77.024	17	4.531		
PRETEST-POSTTEST (PP)	7.042	1	7.042	7.04	ns
ERROR	31.458	3	10.486		
V X PP INT.	1.708	4	0.569	0.35	ns
ERROR	14.458	9	1.606		
Ω X PP INT.	3.083	2	1.542	1.25	ns
ERROR	7.417	6	1.236		
V X Ω X PP INT.	11.667	6	1.944	0.94	ns [a]
ERROR	37.167	18	2.065		

[a] Significance based on Greenhouse-Geisser corrected probability.

Table 10.
Source Table of the Analysis of Covariance
for Mood State Scale Scores.
Data From Experiment One.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
COVARIATE (ELAPSED TIME)	431.091	1	431.091	3.06	ns
ERROR	281.450	2	0.912		
VIEWING CONDITION (V)	7.852	3	2.617	0.32	ns
COVARIATE	0.153	1	0.153	0.02	ns
ERROR	65.888	8	0.236		
FOV (Ω)	6.894	2	3.448	0.89	ns
COVARIATE	1.012	1	1.012	0.26	ns
ERROR	19.322	5	3.864		
V X Ω INT.	44.410	6	7.402	0.75	ns [g]
COVARIATE	3.942	1	3.942	0.40	ns
ERROR	166.892	17	9.817		
PRETEST-POSTTEST (PP)	9.375	1	9.375	0.86	ns
ERROR	32.875	3	10.958		
V X PP INT.	2.208	4	0.736	0.30	ns
ERROR	22.208	9	2.468		
Ω X PP INT.	6.750	2	3.375	3.12	ns
ERROR	6.500	6	1.083		
V X Ω X PP INT.	2.917	6	0.486	0.26	ns
ERROR	34.167	18	1.898		

[g] Significance based on Greenhouse-Geisser corrected probability.

Experiment Two

Six sets of data were obtained for analysis in Experiment Two. They were the same dependent measures obtained in Experiment One, and each was transformed and/or averaged in the same fashion as its Experiment One counterpart prior to analysis. Five sessions were run in which camera separation was fixed at 19.05 cm and magnification was fixed at 2X. Camera convergence was varied at three levels (1.6 meters (Fore), 2 meters (Middle), and ∞ (Parallel), and monoscopic and direct view sessions were also administered.

Haptic Adjustments of Perceived Depth Intervals

Average absolutized errors for haptic adjustment were subjected to a 5 (Viewing Conditions) X 6 (Depth Intervals) repeated measures ANCOVA with observer I_o serving as covariate. Results of this analysis are reported in Table 11. Both Viewing Condition ($F(4,12)=33.26$, $p=.002$) and Rod Depth Interval ($F(5,15)=8.66$, corrected $p=.014$) emerged as significant factors in the analysis.

The Viewing Condition main effect is plotted in Figure 10, and tests of specific mean differences are reported in Table 12. All observers produced similar patterns of response for the five viewing conditions tested. Monoscopic viewing conditions produced haptic error comparable to those found in Experiment One. When cameras were converged in front of the rods at a distance 1.6 meters, haptic accuracy was greatest. When cameras were converged to the middle of the rod workspace, 2 meters

Table 11.
Source Table of the Analysis of Covariance
for Haptic Adjustments of Depth.
Data from Experiment Two.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F	TAIL PROB.
COVARIATE (I_o)	5.140	1	5.140	1.25	ns
ERROR	8.227	2	4.114		
VIEWING CONDITION (V)	449.510	4	112.378	33.26	.002
ERROR	40.550	12	3.379		
DEPTH (D)	75.829	5	15.166	8.66	.014 [g]
ERROR	26.280	15	1.752		
V X D INT.	117.332	20	5.867	3.32	ns [g]
ERROR	105.991	60	1.767		

[g] Significances based on Greenhouse-Geisser corrected probability.

Figure 10. Viewing Condition Main Effect for Haptic Depth Adjustments. Data from Experiment Two.

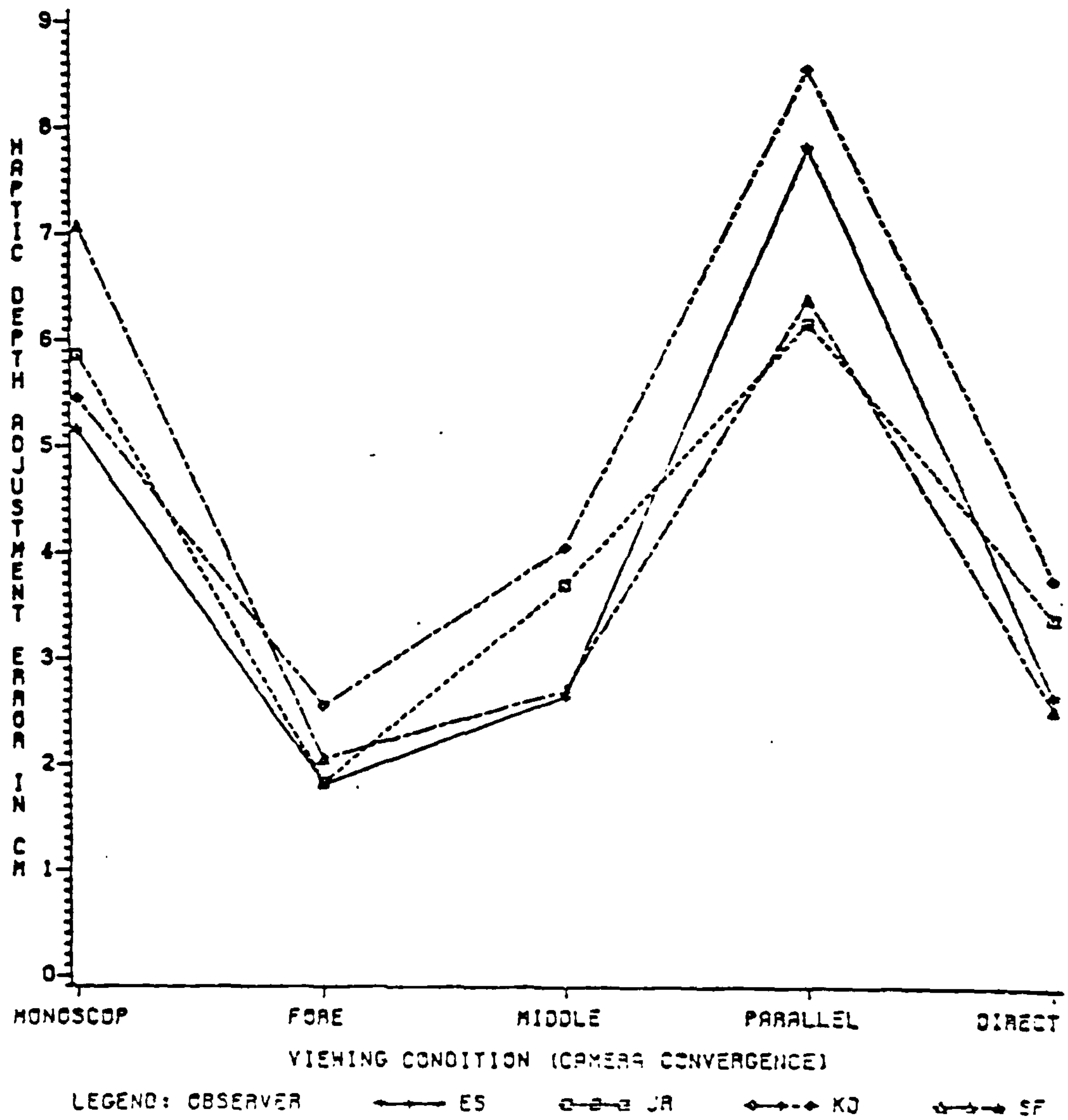


Table 12.
Duncan New Multiple Range Statistic.
Mean Scores for Haptic Adjustment Errors
on the Viewing Condition Main Effect.
Data from Experiment Two.

		:- CAMERA CONVERGENCE -:			
	MONO-SCOPIC	FORE	MIDDLE	PARALLEL	DIRECT VIEW
MEAN SCORE	5.89	2.06	3.10	7.25	3.28
MONOSCOPIC		*	--	--	--
FORE			--	**	--
MIDDLE				--	--
PARALLEL					*
DIRECT VIEW					

* $p < .05$

** $p < .01$

distant, accuracy was approximately 25% lower than under the "Fore" convergence condition, but also closely comparable to accuracy under direct viewing conditions. Paralleling the cameras produced screen disparities which were so large that they could not be fused and produced poorer accuracy than was found under monoscopic viewing conditions.

The depth interval main effect is plotted in Figure 11, and tests of specific cell mean differences are reported in Table 13. The general trend apparent in Figure 11 is that haptic adjustment accuracy declines as size of the depth interval is increased from 5.12 to 25.4 cm. The most accurately estimated interval was 5.12 cm with poorer accuracy found for the null interval.

Verbal Judgments of Perceived Depth Intervals

Average absolutized errors for verbal judgments were subjected to a 5 (Viewing Condition) X 6 (Depth Intervals) repeated measures ANCOVA with observer I_o serving as covariate. Results of this analysis are reported in Table 14. The Viewing Condition main effect ($F(4,12)=10.23$, $p=.019$) was found significant, and is plotted in Figure 12. Tests of specific cell mean differences are reported in Table 15. Inspection of Figure 12 reveals a pattern of results similar but less clear because of greater interobserver variability than those found for haptic adjustments. Verbal judgments for both control conditions (i.e., monoscopic and direct view) were

Figure 11. Rod Depth Interval Main Effect for Haptic Depth Adjustments. Data from Experiment Two.

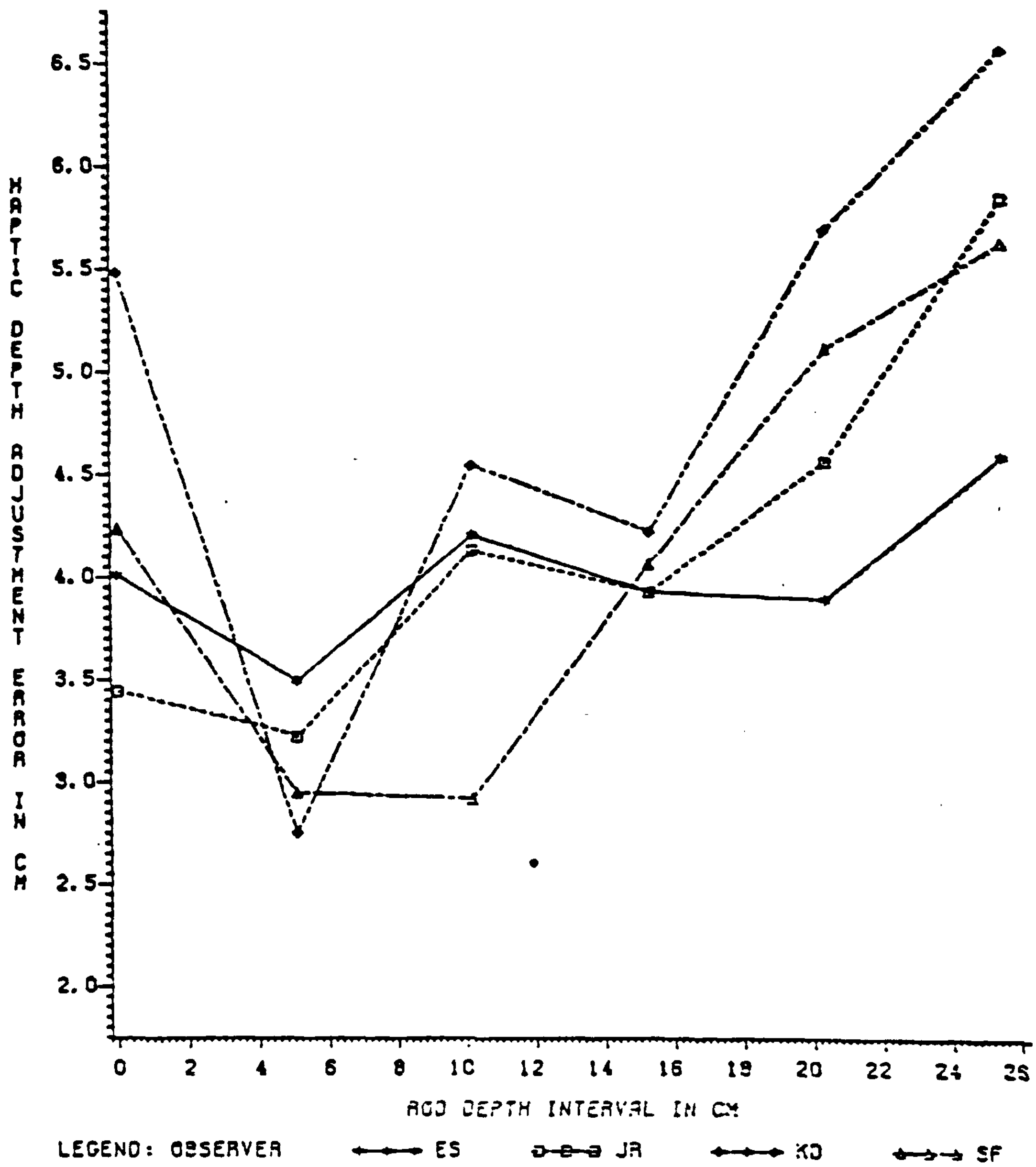


Table 13.
Duncan New Multiple Range Statistic.
Mean Scores for Haptic Adjustment Errors
on the Rod Depth Interval Main Effect.
Data from Experiment Two.

	ROD DEPTH INTERVALS					
	0.00 CM	5.08 CM	10.16 CM	15.24 CM	20.32 CM	25.40 CM
MEAN SCORE	4.29	3.10	3.95	4.04	4.83	5.68
0.00 CM		--	--	--	--	--
5.08 CM			--	--	--	*
10.16 CM				--	--	--
15.24 CM					--	--
20.32 CM						--
25.40 CM						

* $p < .05$

** $p < .01$

Table 14.
Source Table of the Analysis of Covariance
for Verbal Judgments of Depth.
Data from Experiment Two.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F	TAIL PROB.
COVARIATE (I_o)	1.182	1	1.182	0.03	ns
ERROR	122.229	2	61.114		
VIEWING CONDITION (V)	273.288	4	68.322	10.23	.019
ERROR	80.160	12	6.680		
DEPTH (D)	142.726	5	28.545	1.14	ns [g]
ERROR	374.729	15	24.982		
V X D INT.	89.803	20	4.490	3.54	ns [g]
ERROR	76.087	60	1.269		

[g] Significance based on Greenhouse-Geisser corrected probability.

Figure 12. Viewing Condition Main Effect for Verbal Depth Judgments. Data from Experiment Two.

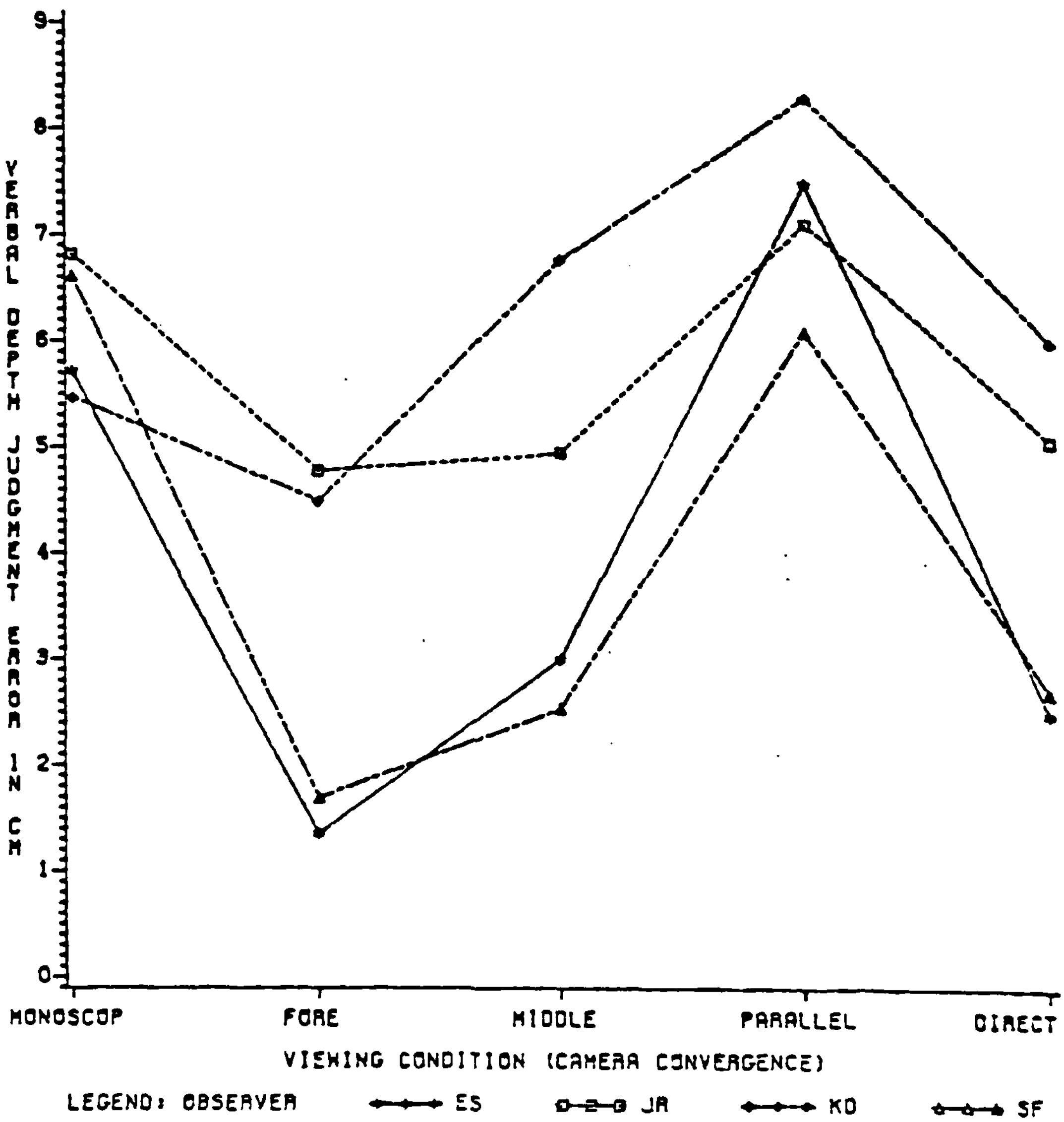


Table 15.
Duncan New Multiple Range Statistic.
Mean Scores for Verbal Judgment Errors
on the Viewing Condition Main Effect.
Data from Experiment Two.

		:- CONVERGENCE POINTS -:			
	MONO-SCOPIC	FORE	MIDDLE	PARALLEL	DIRECT VIEW
MEAN SCORE	6.15	3.08	4.07	7.25	4.32
MONOSCOPIC		--	--	--	--
3.175 CM			--	*	--
6.350 CM				--	--
19.05 CM					--
DIRECT VIEW					

* p < .05

** p < .01

comparable to levels found in Experiment One. For stereo viewing conditions, verbal judgments were most accurate when cameras were converged in front of the rods and least accurate when paralleled. Converging the cameras in front of the rods produced greater accuracy than was found under direct viewing conditions. Converging cameras to the midpoint of the rod workspace produced accuracy closely approximating direct viewing conditions, and paralleling the cameras produced poorer accuracy than monoscopic viewing conditions.

Near-Far Test

Average response times from the near-far test were subjected to a 5 (Viewing Condition) X 2 (Pretest-Posttest) X 2 (Refocus Direction) repeated measures ANCOVA with depth judgment test administration time serving as the covariate. Results of this analysis are reported in Table 16. No significant main effects or interactions emerged from this analysis. Apparently, performance was stable for all viewing conditions tested for both near-to-far and far-to-near refocus adjustments and there was no slowing of response times in the transition from pretest to posttest measures.

Flicker Test

Average flicker fusion thresholds were computed and subjected to a 5 (Viewing Condition) X 2 (Pretest-Posttest) X 2 (Flicker Phase) ANCOVA with depth judgment test time as the

Table 16.
Source Table of the Analysis of Covariance
for Near-Far Test Response Times.
Data from Experiment Two.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
COVARIATE					
(ELAPSED TIME)	0.906	1	0.909	0.99	ns
ERROR	1.832	2	0.912		
VIEWING					
CONDITION (V)	1.821	4	0.455	2.48	ns [g]
COVARIATE	0.627	1	0.627	3.42	ns
ERROR	2.016	11	0.183		
PRETEST-					
POSTTEST (PP)	0.234	1	0.234	2.61	ns
ERROR	0.269	3	0.090		
V X PP INT.	0.670	4	0.168	0.97	ns [g]
ERROR	2.080	12	0.173		
REFOCUS					
DIRECTION (R)	1.815	1	1.815	3.10	ns
ERROR	1.754	3	0.585		
V X R INT.	0.662	4	0.166	0.86	ns [g]
ERROR	2.320	12	0.193		
PP X R INT.	0.413	1	0.413	2.10	ns
ERROR	0.590	3	0.197		
V X PP X R	0.662	4	0.166	1.05	ns [g]
ERROR	1.893	12	0.158		

[g] Significance based on Greenhouse-Geisser corrected probability.

Table 17.
Source Table of the Analysis of Covariance
for Flicker Fusion Thresholds.
Data from Experiment Two.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
COVARIATE (ELAPSED TIME)	288.803	1	288.803	5.78	ns
ERROR	99.871	2	49.935		
VIEWING CONDITION (V)	20.061	4	5.015	0.79	ns [g]
COVARIATE	0.179	1	0.179	0.03	ns
ERROR	69.520	11	6.320		
PRETEST-POSTTEST (PP)	6.938	1	6.938	2.96	ns
ERROR	7.032	3	2.344		
V X PP INT.	10.017	4	2.504	0.67	ns [g]
ERROR	44.651	12	3.721		
PHASE (PH)	0.872	1	0.872	1.46	ns
ERROR	1.787	3	0.596		
V X PH INT.	4.477	4	1.119	1.13	ns [g]
ERROR	11.937	12	0.995		
PP X PH INT.	0.146	1	0.146	0.13	ns
ERROR	3.472	3	1.157		
V X PP X PH	9.086	4	2.272	1.11	ns [g]
ERROR	24.456	12	2.038		

[g] Significance based on Greenhouse-Geisser corrected probability.

covariate. Results of this analysis are reported in Table 17. No significant main effects or interactions emerged from this analysis, once again suggesting stable performance and no support for rejection of the null hypothesis for eyestrain.

Questionnaire

No significant main or interactive effects emerged from a 5 (Viewing Conditions) X 2 (Pretest-Posttest) ANCOVA (with depth judgment test time as covariate) which was performed on the mood scale scores from Experiment Two. The results of this analysis are reported in Table 18. No significant effects were found on the eyestrain scale (see Table 19), although there was a trend in the Viewing Condition X Pretest-Posttest interaction ($F(4,12)=4.89$, corrected $p=.06$) which merits comment. The interaction is plotted in Figure 13. If one considers posttest scores only, each observer appears to experience more discomfort and eyestrain for the parallel camera viewing condition than for any of the other viewing conditions tested. This contention is supported by spontaneous verbal reports from three observers that this condition produced considerably more discomfort th-n any of the other conditions tested to date. The effect is possibly mitigated by the fact that three of four observers also reported lowest levels of eyestrain on the pretest for that session.

Table 18.
Source Table of the Analysis of Covariance
for Eyestrain Scale Scores.
Data From Experiment Two.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
COVARIATE (ELAPSED TIME)	2.238	1	2.138	0.34	ns
ERROR	142.397	2	71.199		
VIEWING CONDITION (V)	65.923	4	16.481	5.00	ns [g]
COVARIATE	1.918	1	1.918	0.58	ns
ERROR	36.232	11	3.294		
PRETEST-POSTTEST (PP)	0.625	1	0.625	0.27	ns
ERROR	6.875	3	2.292		
V X PP INT.	14.250	4	3.563	4.89	ns [g]
ERROR	8.750	12	0.729		

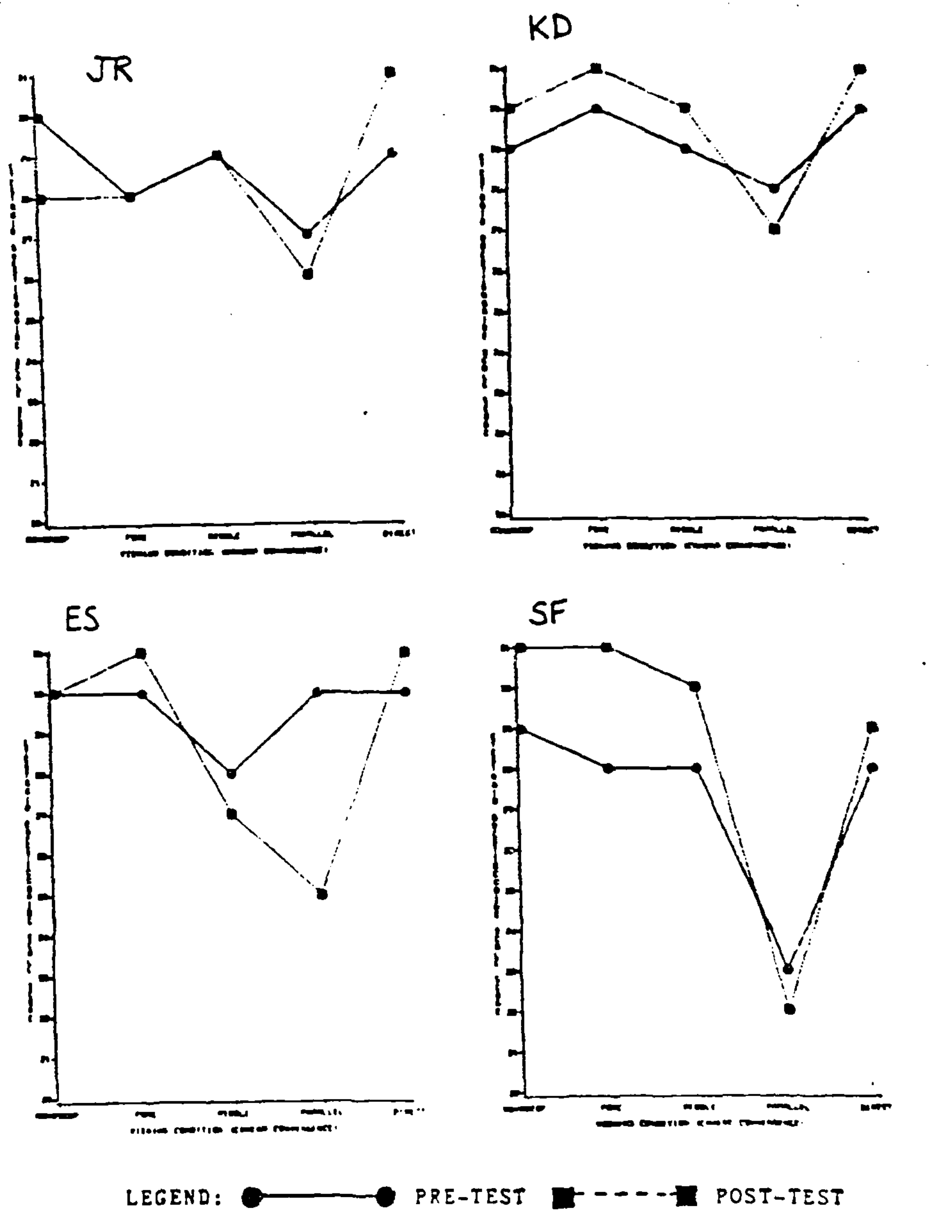
[g] Significance based on Greenhouse-Geisser corrected probability.

Table 19.
Source Table of the Analysis of Covariance
for Mood State Scale Scores.
Data From Experiment Two.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
COVARIATE (ELAPSED TIME)	90.678	1	90.678	1.27	ns
ERROR	142.397	2	71.199		
VIEWING CONDITION (V)	44.792	4	11.197	2.50	ns [a]
COVARIATE	0.181	1	0.181	0.04	ns
ERROR	49.369	11	4.488		
PRETEST-POSTTEST (PP)	7.225	1	7.225	1.63	ns
ERROR	13.275	3	4.425		
V X PP INT.	17.650	4	4.413	2.89	ns [a]
ERROR	18.350	12	1.529		

[a] Significance based on Greenhouse-Geisser corrected probability.

Figure 13. Viewing Condition X Pre-Post Interaction for Eyestrain Questionnaire Scale Scores. Data from Experiment Two.



Experiment Three

Since the near-far test and the flicker test were not included in Experiment Three, measures on four dependent variables were obtained for analysis: 1) the mood scale, 2) the eyestrain scale, 3) haptic adjustments, and 4) verbal judgments of depth. Data were transformed and/or averaged in the same manner as their counterparts in Experiment One and subjected to repeated measures ANCOVAs. Analyses were of the same form as was used in Experiment Two with three levels of camera separation (3.175 cm, 6.35 cm, and 19.05 cm) substituted for the convergence conditions employed in Experiment Two.

Haptic Adjustments of Perceived Depth Intervals

The ANCOVA for haptic adjustments (reported in Table 20) revealed significant main effects for Viewing Condition ($F(4,16)=19.78$, corrected $p=.002$) and for rod depth interval ($F(5,20)=7.99$, corrected $p=.020$). The Viewing Condition main effect is plotted in Figure 14, and tests of specific cell mean differences are reported in Table 21. Inspection of Figure 14 reveals the same basic pattern of results that was found for the viewing condition main effect in Experiment One. Stereo TV viewing conditions were superior monoscopic ones. Two observers (KD and JB) produced data points for the 3.175 cm camera separation which contradict this general trend. Since JB was an inexperienced observer, her data were generally the least accurate in Experiment Three for all TV viewing conditions. She did, however, produce data closely comparable to that of the

Table 20.
Source Table of the Analysis of Covariance
for Haptic Adjustments of Depth.
Data from Experiment Three.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F	TAIL PROB.
COVARIATE (I_o)	84.039	1	84.390	1.75	ns
ERROR	144.190	3	48.063		
VIEWING CONDITION (V)	1304.991	4	326.248	19.78	.002 [g]
ERROR	263.864	16	16.492		
DEPTH (ΔR)	249.588	5	49.918	7.99	.020 [g]
ERROR	124.997	20	6.250		
V X ΔR INT.	202.654	20	10.132	2.80	ns [g]
ERROR	289.939	80	3.624		

[g] Significance based on Greenhouse-Geisser corrected probability.

Figure 14. Viewing Condition Main Effect for Haptic Depth Adjustments. Data from Experiment Three.

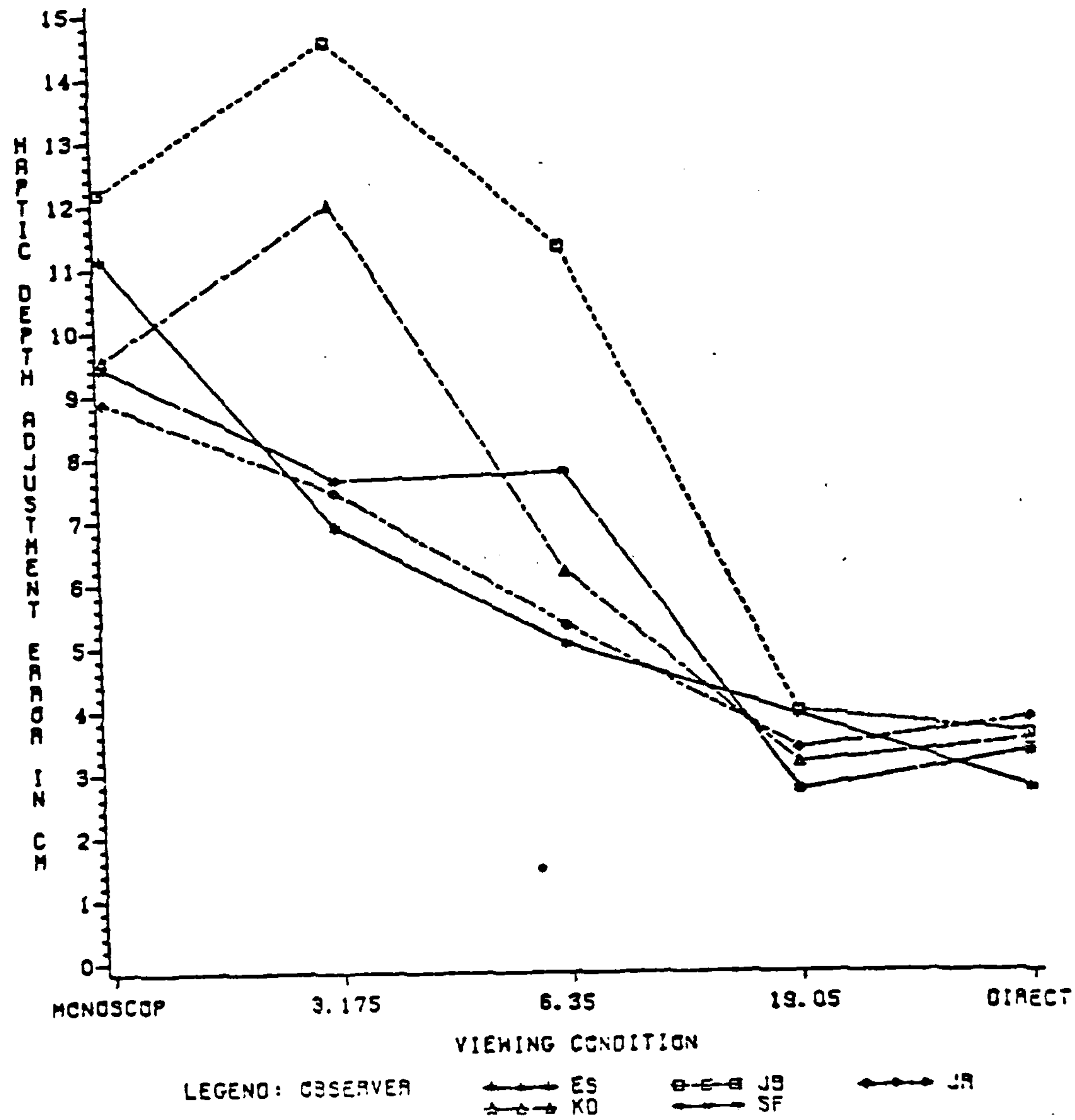


Table 21.
Duncan New Multiple Range Statistic.
Mean Scores for Haptic Adjustment Errors
on the Viewing Condition Main Effect.
Data from Experiment Three.

	MONO-SCOPIC	3.175 CM	6.35 CM	19.05 CM	DIRECT VIEW
MEAN SCORE	10.23	9.70	7.12	3.40	3.38
MONOSCOPIC		--	--	*	*
3.175 CM			--	*	*
6.350 CM				--	--
19.05 CM					--
DIRECT VIEW					

* $p < .05$

** $p < .01$

other experienced observers. There was no obvious difference in overall accuracy for the more experieced males versus the less experienced females (KD and SF). Largest deviations from the group mean for experienced observers (all except JB) occurred for KD at the 3.175 cm separation and for SF at the 6.350 cm separation.

The rod depth interval main effect is plotted in Figure 15 and reveals a trend very similar to that found in Experiment Two. Tests of specific cell mean differences within this effect are reported in Table 22. Greatest accuracy was obtained for the 5.08 cm rod depth interval with gradual decreases in accuracy for longer depth intervals out to the largest interval tested (25.4 cm).

Accuracy for the null depth interval was substantially poorer and more variable than that observed with the 5.08 cm depth interval. The inexperienced observer, JB, produced a similar pattern of data at a lower level of accuracy.

Verbal Judgments of Perceived Depth Intervals

An ANCOVA of absolutized verbal judgments also produced a pattern of results similar to those found in Experiment One. Results of this analysis are reported in Table 23. Both the Viewing Condition and the Viewing Condition ($F(4,16)=8.05$, $p < .001$) by Depth Interval interactions ($F(20,80)=3.81$, corrected $p=.042$) emerged as significant factors in the analysis. The

Figure 15. Rod Depth Interval Main Effect for Haptic Depth Adjustments. Data from Experiment Three.

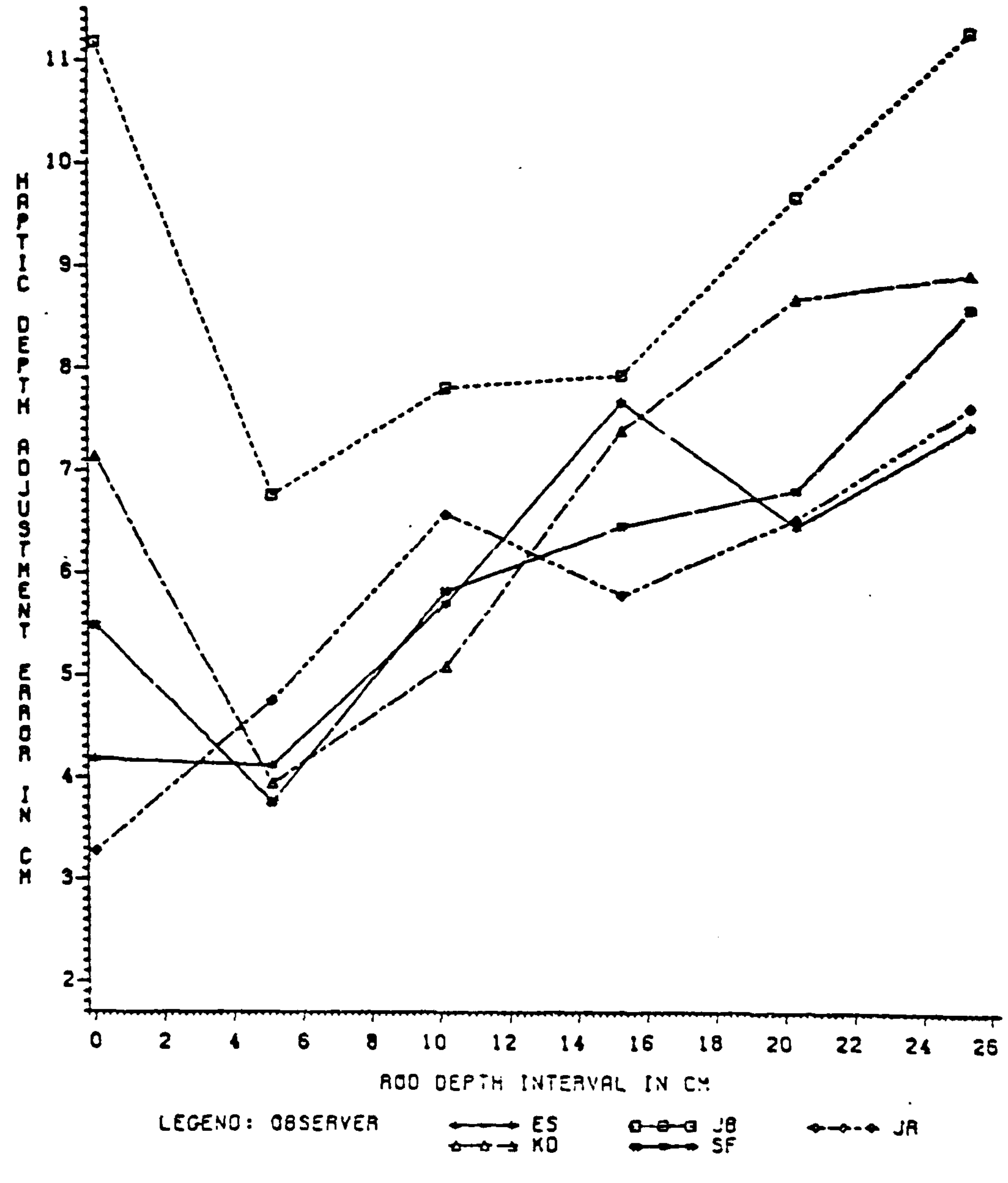


Table 22.
Duncan New Multiple Range Statistic
Mean Scores for Haptic Adjustment Errors
on the Rod Depth Interval Main Effect.
Data from Experiment Three.

	ROD DEPTH INTERVALS					
	0.00 CM	5.08 CM	10.16 CM	15.24 CM	20.32 CM	25.40 CM
MEAN SCORE	6.25	4.66	6.21	7.05	7.64	8.80
0.00 CM		--	--	--	--	--
5.08 CM			--	--	--	*
10.16 CM				--	--	--
15.24 CM					--	--
20.32 CM						--
25.40 CM						

* p < .05

** p < .01

Table 23.
Source Table of the Analysis of Covariance
for Verbal Judgments of Depth.
Data from Experiment Three.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F	TAIL PROB.
COVARIATE (I_o)	61.852	1	61.852	0.37	ns
ERROR	495.563	3	165.188		
VIEWING CONDITION (V)	829.065	4	207.266	8.05	<.001
ERROR	411.885	16	25.743		
DEPTH (ΔR)	169.658	5	33.932	0.54	ns [g]
ERROR	1256.844	20	62.842		
V X ΔR INT.	293.808	20	14.690	3.81	.042 [g]
ERROR	308.482	80	3.856		

[g] Significance based on Greenhouse-Geisser corrected probability.

Viewing Condition main effect for verbal depth judgments is plotted in Figure 16. Tests of specific cell mean differences wiithin this effect are reported in Table 24. Interobserver differences are greater than with haptic judgments but the same general trend appears in the plot. Stereo TV views produce more accurate reports than monoscopic views (with the exception of KD and JB for the 3.175 cm camera separation) and there is a trend toward greater accuracy for wider interaxial camera separations. Accuracy for the 19.05 cm camera separation is comparable -hat found under direct view control conditions. The Viewing Condition by Depth Interval interaction was plotted for each observer in Figure 17. So much heterogeneity of patterning across observers exists for this effect that there seems little justification for considering the effect to reflect anything more than a statistical artifact.

Questionnaire

ANCOVAs for the mood scale and eyestrain scale scores found no significant F-ratios for any main or interactive effects. Source tables for eyestrain scale and mood scale scores are reported in Tables 25 and 26, respectively.

Experiment Four

Data obtained in Experiment Four were analysed in the same way as data analysed in Experiment Three. The only difference between the two experiments was in perceptual information

Figure 16. Viewing Condition Main Effect for Verbal Depth Judgments. Data from Experiment Three.

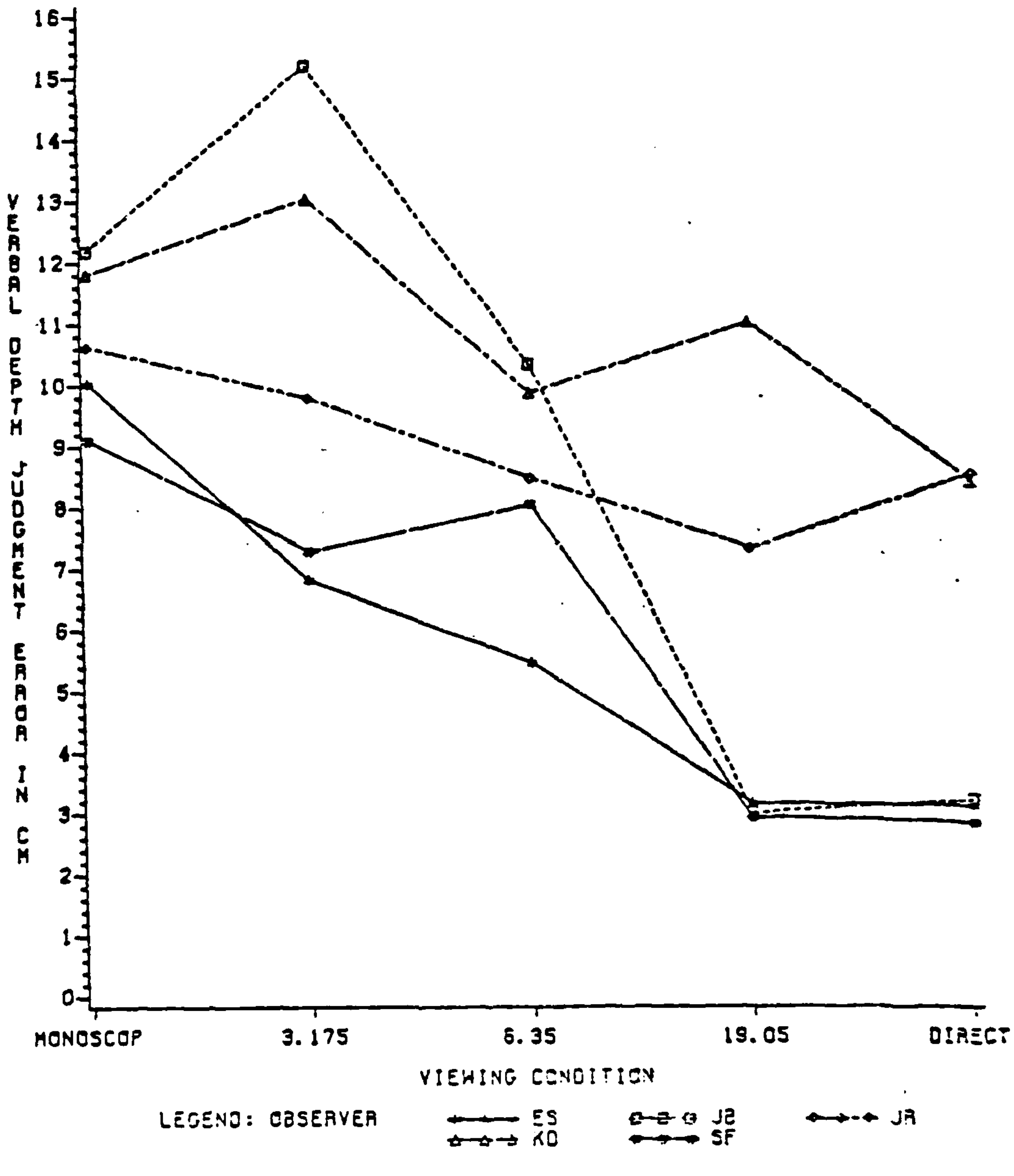


Table 24.
Duncan New Multiple Range Statistic.
Mean Scores for Verbal Judgment Errors
on the Viewing Condition Main Effect.
Data from Experiment Three.

		:- CAMERA SEPARATION -:			
	MONO-SCOPIC	3.175 CM	6.35 CM	19.05 CM	DIRECT VIEW
MEAN SCORE	10.75	10.42	8.43	5.48	5.22
MONOSCOPIC		--	--	--	--
3.175 CM			--	--	--
6.350 CM				--	--
19.05 CM					--
DIRECT VIEW					

* p < .05

** p < .01

Figure 17. Rod Depth Interval Main Effect for Haptic Depth Adjustments. Data From Experiment Four.

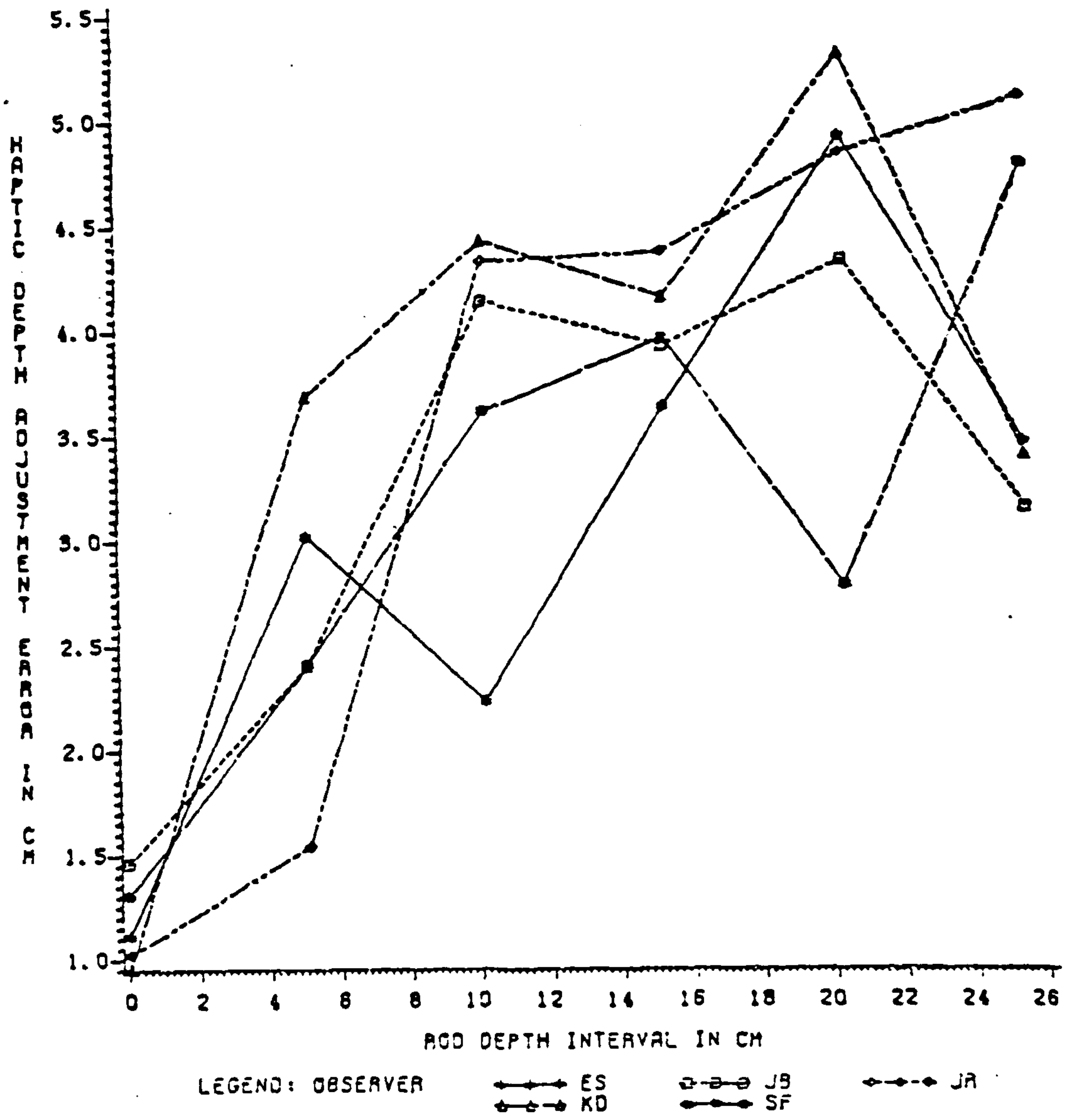


Table 25.
Source Table of the Analysis of Covariance
for Eyestrain Scale Scores.
Data From Experiment Three.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
COVARIATE (ELAPSED TIME)	22.858	1	22.858	1.26	ns
ERROR	54.622	3	18.207		
VIEWING CONDITION (V)	30.979	4	7.745	2.72	ns
COVARIATE	1.026	1	1.026	0.36	ns
ERROR	42.694	15	2.846		
PRETEST-POSTTEST (PP)	10.580	1	10.580	3.61	ns
ERROR	11.720	4	2.930		
V X PP INT.	5.320	4	1.330	0.89	ns
ERROR	23.880	12	1.493		

Table 26.
Source Table of the Analysis of Covariance
for Mood State Scale Scores.
Data From Experiment Three.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	TAIL PROB.
COVARIATE (ELAPSED TIME)	114.438	1	114.438	0.92	ns
ERROR	373.442	3	124.481		
VIEWING CONDITION (V)	12.580	4	3.145	0.73	ns [g]
COVARIATE	5.002	1	5.002	1.16	ns
ERROR	64.518	15	4.301		
PRETEST-POSTTEST (PP)	0.320	1	0.320	1.19	ns
ERROR	1.080	4	0.270		
V X PP INT.	21.080	4	5.270	3.92	.02
ERROR	21.520	16	1.345		

[g] Significance based on Greenhouse-Geisser corrected probability.

available in imagery from the remote environment.

Haptic Adjustments of Perceived Depth Intervals

The ANCOVA for haptic adjustments (see Table 27) revealed only one significant source of variation, the depth interval main effect ($F(5,20) = 12.58$, corrected $p = .001$). This effect is plotted in Figure 18. and tests for specific cell mean differences are reported in Table 28. As with the results of Experiments Two and Three, there was a general trend toward increased error for the longer depth intervals. Unlike results from earlier studies, the null depth interval produced more accurate responses than any of the other depth intervals tested.

Verbal Judgments of Perceived Depth Intervals

An ANCOVA for verbal judgments failed to reveal any statistically significant effects. Results of this analysis are reported in Table 29.

Questionnaire

ANCOVA's for the mood and eyestrain scales failed to provide any evidence of change as a result of exposure to the various viewing conditions tested in this study.

Table 27.
Source Table of the Analysis of Covariance
for Haptic Adjustments of Depth.
Data from Experiment Four.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F	TAIL PROB.
COVARIATE (I_o)	0.120	1	0.120	0.05	ns
ERROR	7.825	3	2.608		
VIEWING CONDITION (V)	9.120	4	2.300	1.24	ns
ERROR	29.644	16	1.853		
DEPTH (ΔR)	187.542	5	37.508	12.58	.001 [g]
ERROR	59.613	20	2.981		
V X ΔR INT.	25.626	20	1.281	0.95	ns [g]
ERROR	107.627	80	1.345		

[g] Significance based on Greenhouse-Geisser corrected probability.

Figure 18. Viewing Condition X Depth Interval Interaction for Verbal Depth Judgments. Data From Experiment Three.

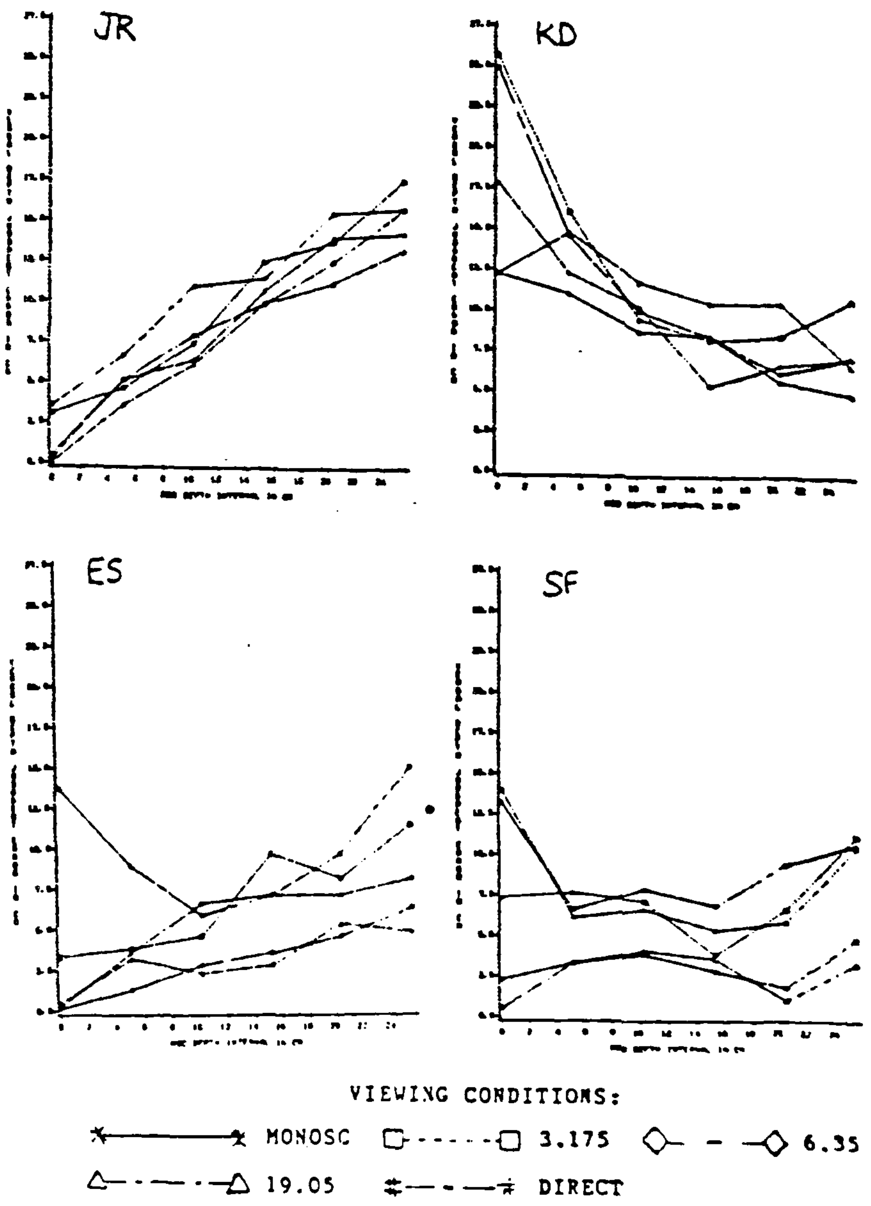


Table 28.
Duncan New Multiple Range Statistic.
Mean Scores for Haptic Adjustment Errors
on the Rod Depth Interval Main Effect.
Data from Experiment Four.

	ROD DEPTH INTERVALS					
	0.00 CM	5.08 CM	10.16 CM	15.24 CM	20.32 CM	25.40 CM
MEAN SCORE	1.17	2.61	3.75	4.02	4.45	3.99
0.00 CM		--	--	*	*	--
5.08 CM			--	--	--	--
10.16 CM				--	--	--
15.24 CM					--	--
20.32 CM						--
25.40 CM						

* $p < .05$

** $p < .01$

Table 29.
Source Table of the Analysis of Covariance
for Verbal Judgments of Depth.
Data from Experiment Four.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F	TAIL PROB.
COVARIATE (I_o)	21.525	1	21.525	0.11	ns
ERROR	582.932	3	194.311		
VIEWING CONDITION (V)	43.627	4	10.907	0.83	ns [g]
ERROR	210.705	16	13.169		
DEPTH (ΔR)	574.526	5	114.905	4.30	ns [g]
ERROR	535.054	20	26.753		
V X ΔR INT.	54.725	20	2.736	1.71	ns [g]
ERROR	127.988	80	1.600		

[g] Significance based on Greenhouse-Geisser corrected probability.

DISCUSSION

Experiment One

Results of Experiment One support the hypothesis that stereo TV provides valuable perceptual information which significantly enhances an observer's ability to perceive three-dimensional spatial relationships (i.e., depth intervals) in remote environments. This finding is supported by a substantial body of evidence demonstrating increased depth resolution with stereo displays (Upton and Strother, 1972; Fugitt and Uhrich, 1973; Shields et al, 1975; Zamarin, 1976; Pepper and Cole, 1978; Pepper, Cole, and Pinz, 1981; Spain and Cole, 1982). However, these previous studies provided no evidence which inevitably leads to the conclusion that results on a depth resolution task will predict those of a depth scaling task. If disparities alone were a completely dominant cue for the perception of depth relationships as the simple geometrical model of stereopsis assumes, it would be reasonable to predict enhancements in depth resolution since a constant physical depth interval would produce greater disparities at higher lens magnifications and/or camera separations. While human stereoacuity thresholds remain relatively constant over repeated measurements, the physical depth interval necessary to provide threshold disparity would vary as a direct function of camera parameters of camera separation and magnification. When a scaling of space in the remote environment is involved, one would expect to see over- or under-estimates of depth extent depending on the magnification or minification of disparities with respect to their orthostereoscopic values. Thus, if disparities were doubled by manipulation of viewing system parameters, one would expect an observer to experience twice as much depth sensation in a given scene. Put most simply, an object of unit depth would be perceived as having two units of depth. Such a pattern of results was not found in Experiment One. The series of experiments reported herein was an initial effort toward understanding an as yet little explored aspect of remote presence, an aspect intermediate between simple depth resolution and active manipulation in the remote environment. Rather than asking the observer whether depth intervals between stimulus objects were present or absent or requiring him to perform a complex manipulation in the remote environment, the approach taken was to measure how large or small objective depth intervals appeared to be under the range of viewing conditions investigated.

Whereas earlier applied studies with stereo TV systems (e.g., Pesch, 1968; Tewell, et al, 1974; Smith, et al, 1979) provided substantial evidence of stereo TV's advantages for remote manipulation, the level of complexity associated with control dynamics of manipulators and the interactive nature of manipulator tasks have unfortunately confounded efforts to understand perception of remote environments through stereo TV systems. An orthostereoscopic condition in which retinal disparities were matched to those occuring under direct-view conditions produced less accurate performance than the direct view condition. Though not statistically significant, performance under orthostereoscopic TV views was consistently less accurate across all observers. Similar results have been found in several studies of depth resolution which included a direct view control condition (e.g., Zamarin, 1976b; Pepper, Cole, and Pinz, 1981; Pepper, Cole, and Spain, 1983).

As disparities were increased in the present experiment by widening camera separation, there was a resulting increase in each observer's accuracy in gauging depth intervals within the remotely imaged scene. Following testing sessions, observers spontaneously reported that the largest camera separation tested (19.05 cm) provided the most "natural appearing" views of the remote scene. Smaller (i.e., 3.175 and 6.35 cm) camera separations produced imagery which observers reported to appear flattened in depth. Results for both the haptic adjustments and verbal judgments of perceived depth measured in Experiment One demonstrated that increasing disparities beyond their orthostereoscopic values by an enhancement ratio of 3.0 produced by a combination of 1X magnification and 19.05 cm camera separation resulted in depth estimates which most closely approximated those found under direct viewing conditions. Studies by Grant, et al, 1973, Tewell, et al, 1974, and Shields, et al, 1975 utilized camera separations of 15.24 cm. Of these early studies only Grant, et al varied camera separation while holding magnification constant at 1.02x finding a very slight improvement in performance (task times) in the transition from 15.24 cm to 20.32 cm camera separations and shortest task times when cameras were separated by 45.72 cm (18 inches). This is not surprising when one considers that cameras were converged to the distance of one of the rods at all times. Zamarin (1976b), however, in the largest and most complete investigation to date of the impact of viewing system parameters on depth resolution, found that a 17.8 cm camera separation across a range of camera convergence conditions similar to that tested in the present study produced faster and more accurate adjustments than any of the other camera separations measured. Although the largest camera separation tested was 12.7 cm, results of Cole, et al's (1981) study are in accordance with those found by Zamarin. Spain and Cole's (1982) study of depth resolution with a helmet mounted stereo TV display also suggested that depth resolution is more acute under 1X magnification and 19.05 cm camera separation than under smaller camera separations.

Two of the conditions tested in Experiment One (3X magnification with 6.35 cm camera separation and 1X magnification with 19.05 cm camera separation) provided stereo imagery with a 3.0 disparity exaggeration ratio, but the former produced greater depth matching accuracy for all four observers tested. Why this occurred is as yet unclear, but the answer must lie in the patterning of cues inherent in the televised scene, and in the rules by which the human visual system weights various sensory inputs prior to deriving depth percepts. It should be noted that the effect of camera separation would have been even more pronounced in the analysis of Experiment One's results if the 3X magnification condition had been excluded. The combination of 3X magnification and 19.05 cm camera separation produced disparities which were nine times their orthostereoscopic values. For the largest depth interval tested (i.e., 25.4 cm) this produced a disparity difference between the two rods which was on the order of 64 arcminutes making it extremely difficult, if not impossible, for observers to fuse the disparate images of both rods simultaneously. Following the session in which these viewing conditions were tested, the two inexperienced female observers spontaneously commented on their difficulties in maintaining fusion on some testing trials. Even in light of this evidence suggesting that difficulties in fusion brought about a decline in accuracy, one might possibly argue that it was not the extreme exaggeration of disparities which degraded performance, but the widening angular separation between screen images of the targets to be judged in depth. Clearly, increasing lateral angular separation between targets in a Howard-Dolman type task does degrade depth resolution under direct viewing conditions (Graham, et al, 1949). However, if this were the sole or primary contributory factor to the effect apparent in the 3X magnification with 19.05 cm camera separation viewing condition, one would expect to see similar decreases in performance for other conditions in which 3X magnification was utilized (i.e., monoscopic, 3.175 cm, and 6.35 cm camera separations). Such was clearly not the case as a review of Figure 8 reveals. In fact, three of the four observers tested were most accurate under 3X magnification with its attendant wide angle of screen separation between rods under the monoscopic viewing condition. Obviously, there is a factor (or factors) other than angular separation of targets to be compared which is responsible for producing these differences in depth estimation accuracy. This conclusion is supported by the finding of no significant effect for magnification for haptic adjustments and verbal judgments of depth. It is further supported by Zamarin's finding of no significant effect for camera magnification on a depth resolution task under similar stimulus conditions.

Average administration time for 60 depth judgement trials across all 13 sessions was 23.3 minutes (standard error = 2.43 minutes). This was barely one-fifth the total amount of time required to produce statistically significant evidence of visual fatigue with NF and FF measures in previous studies employing these measures (e.g., Collins and Pruen, 1959; Simonson and Enzer, 1941). Due to the unusual viewing conditions (enhanced or diminished disparities, distortions of normal perspective, mismatches between convergence and accommodation) which occurred during stereo TV viewing and subjective reports of discomfort and eyestrain from stereo TV users following brief (i.e., less than 30 minute) exposure (Liebowitz and Sulzer, 1965), it was hypothesized that substantial shifts in visual performance on the

NF and FF tests could be induced with relatively brief exposure to stereo TV displays. To the contrary, no evidence was found on either the NF or the FF tests to support the hypothesis that stereo TV viewing under any of the viewing conditions tested in Experiment One caused or contributed to observer eyestrain. Consequently, no differentiation between fatigue in central or peripheral sensory mechanisms was possible on the basis of the results of Experiment One. Informal discussions with observers subsequent to testing sessions supported the conclusion that no appreciable eyestrain was produced under the viewing conditions tested. The two less experienced, female observers reported that the hour spent in a typical testing session was less strenuous for their eyes than an hour spent working at their normal jobs. They also, on occasion, spontaneously reported that they were returning to their jobs feeling more relaxed than they felt at the beginning of testing sessions. Liebowitz and Sulzer suggested that slight misalignments of retinal images due to ocular phorias and aniseikonia contributed to visual fatigue in observers of stereo displays though this proposition has never been put to test. In future experiments, individuals with slight, but measurable, eye muscle imbalances or aniseikonia should be compared with normals across various viewing system configurations for evidence of visual fatigue.

In summary, results of Experiment One supported previous findings of practical advantages for using stereo TV to perform tasks which require accurate scaling of depth dimensions in a remotely televised environment. They also supported the practice of using increased camera separation to enhance the accuracy of depth perception, a finding which contradicts the orthostereoscopic strategy for configuring a stereo TV camera system to provide natural-appearing imagery. Magnification was not found to exert a statistically significant effect on depth estimation accuracy. This finding contradicts the simple geometrical model of depth perception with stereo TV displays because, like camera separation, disparities are directly varied by lens magnification. In addition to increasing disparities, however, magnification narrows an observer's effective field of view of the remote scene and increases the angular separation between objects in the televised scene. Though not statistically significant, the pattern of results found in Experiment One suggests that magnification contributed to a decrease in accuracy when high magnification was used in conjunction with wide camera separation. Under some stimulus conditions the combination of wide camera separation and lens magnification produced disparities which were very difficult if not impossible for observers to fuse. No evidence was found to suggest that the range of stereo TV parameters tested contributed to observer eyestrain over an average 23.3 minute exposure time.

Experiment Two

Results of Experiment Two conclusively demonstrated that camera convergence angle exerted a statistically significant effect on the accuracy of observer's judgments of relative depth, both haptic and verbal. Most accurate perception of depth intervals was produced when the cameras were converged in front of the workspace within which the stimuli to be compared in depth were positioned. This camera convergence condition produced uncrossed disparities for the stimulus rods which the visual system interpreted as appearing to be located in "screen space", that is, behind the frame of the "stereo window" (i.e., the border of the optically superimposed monitor screens). This viewing condition is "natural" in the sense that it occurs frequently in everyday experience -- whenever one looks out of a window onto a scene. Less accurate depth interval estimation was found when cameras were converged to the center of the workspace within which stimulus rods were positioned. This convergence condition produced uncrossed disparities for rods located beyond the convergence point and crossed disparities for rods located nearer than the convergence point. It was identical to the 2X magnification with 19.05 cm camera separation viewing condition tested in Experiment One and produced very similar levels of performance. Video images of the stimulus rods extended across the entire vertical length of the display screens, their upper and lower ends being contiguous with the upper and lower borders of the stereo window. Whenever rods with crossed disparities were displayed in this way a perceptual conflict occurred. The stereo window clearly overlapped screen images of the rods. This provided the observer with a paradoxical viewing situation in which disparities signaled that the rods were nearer than the depth plane of the stereo window while interposition cues signaled that the rods were overlapped by the screen. Studies performed under direct viewing conditions (i.e., Gregory, 1970) suggest that when conflict between interposition and disparities occurs, interposition cues tend to dominate in perception, particularly in the region immediately adjacent to the overlap. This situation would, of course, detract from accurate perception of the remote scene by altering the perceived depth of objects having crossed disparities. In any event, the above discussion is largely speculative and remains to be confirmed by future studies in which objects having boundaries contiguous and non-contiguous with the screen frame are compared and sharp contours of the stereo window are effectively eliminated either by blurring or by expanding the display field of view and thereby projecting boundaries of the stereo window onto more peripheral retinal regions.

By far, the least accurate depth estimates were found in Experiment Two under the paralleled camera viewing condition. Since 2X magnification and the 19.05 cm camera separation were employed throughout all testing sessions in Experiment Two, paralleling the camera axes not only produced crossed disparities for the rods, but also produced disparities so large that they were impossible for observers to fuse simultaneously for even the smallest rod depth interval tested (5.08 cm). The paralleled camera viewing condition produced spontaneous complaints from observers about the great difficulty and stress involved in

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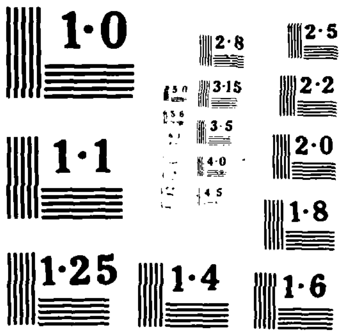
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performing the depth estimation task. Though not a statistically significant effect, performance for 3 of the 4 observers tested was found to be poorer under the paralleled camera stereo condition than under the monoscopic viewing condition. Thus, even though disparities within Ogle's range of patent stereopsis were present in the imagery, they may have provided only distracting information for performance of the depth estimation tasks. One obvious implication for the design of practical stereo TV systems is to configure the cameras so that objects of interest at various distances from the cameras do not provide such large disparities that they cannot be fused by an observer. In the case where objects may occasionally intrude between cameras and objects of interest and produce unfusable crossed disparities, it would be advisable to provide a "stereo kill" function that switches the stereo display to a monoscopic view. So long as stereo TV displays continue to have high contrast screen borders, providing observers with a sharply defined stereo window, it also appears advisable to provide the observer with a means of remotely adjusting camera convergence from 20° to parallel so that objects of interest produce uncrossed screen disparities.

Even with three of four observers spontaneously complaining about the difficulty of performing the depth perception task under the parallel camera viewing conditions, no evidence of eyestrain was found on any of the three measures administered immediately prior to and following depth perception trials.

Average depth perception test time in Experiment Two was 20.0 minutes.

Experiment Three

Experiment Three was designed to determine whether the relationships that were found in Experiment One between camera separation and accuracy of depth estimation would hold for a slightly more complex remote scene. The only difference between stimulus conditions used in Experiment One and those used in Experiment Three was the presence of a patterned plane behind the null point for the rods. In general, results of Experiment Three were quite similar to those found for Experiment One. Stereo TV viewing conditions produced more accurate depth estimates than the monoscopic control condition and larger values of camera separation also produced increases in accuracy for both haptic adjustments and verbal estimates of depth. More between-observer variability is evident for the verbal report measure than on the haptic adjustment measure, a pattern not readily discernable in Experiment One most likely because of differences between experienced males and relatively inexperienced females on the haptic measure, but quite apparent in the results of Experiment Two.

The reasoning behind assessing depth perception with the clearly defined repetitive background pattern was not to introduce additional cues to depth and measure the amount by which they promoted accuracy. Rather, repetitive patterning was introduced to determine whether the introduction of ambiguous cues to depth in the background plane would result in less accurate depth estimates. It has long been known (e.g., see Helmholtz, 1962, p. 316) that horizontally repeating patterns frequently give rise to false fusions (convergence not appropriate to the true distance of the repeating pattern such that images from different features are projected onto corresponding parts of the eyes) and distorted perceptions of depth intervals (Ono, Seabrook, & Mitson, 1973) under direct viewing conditions. Whether this was an important determinant of performance under stereo TV viewing conditions required empirical study. Another possible source of degraded performance with stereo TV displays was an optical distortion that occurs when cameras are widely separated and converged to near distances (as they were in Experiment Three). This effect, commonly known as "keystoning" among stereophotographers, produced vertical disparities for objects in the lateral periphery of stereo imagery. The interested reader may consult Ferwerda (1982) for a clear description of keystoning and arguments against converging stereo cameras. Keystoning was not present to any appreciable extent in either Experiments One or Two because of the vertical orientation of the rods and the absence of pattern in the background plane. It is argued by stereophotographers, primarily on an aesthetic basis, that keystoning produces unappealingly distorted imagery and contributes to eyestrain. One oft-quoted rule-of-thumb in stereophotography states that if one must converge cameras, the distance of the convergence point from the cameras should be no less than thirty times greater than the interaxial separation between the cameras (Ferwerda, 1982; Valyus, 1966). This "one-in-thirty" rule was clearly violated by the camera convergence angle utilized in Experiment Three. Since the camera convergence point was 1.6 meters distant and cameras were separated by approximately .2 meter, the ratio of separation to convergence distance was only one-to-eight. There was, however, no evidence produced by Experiment Three which suggested that keystoning brought about any substantial decrements in depth interval estimation when the results of Experiment Three are compared to those of Experiment One.

While accuracy was generally lower under Experiment Three testing conditions than it was under comparable conditions employed in Experiment One (2X magnification with 19.05 cm camera separation), this general decrement in performance was probably not due to keystoning because similarly proportioned decrements occurred for the monoscopic and direct viewing conditions, neither of which were influenced by keystoning. It is more likely that the decrements which appear to have occurred in the transition from Experiment One to Experiment Three occurred as a result of false fusions of the repetitive background and subsequent distortions. Comparisons of the patterns of results for Experiments One and Three do not suggest an interactive influence on remote depth perception for repetitive background patterns and the range of stereo camera separations tested.

The depth interval main effect for haptic adjustments was similar to that found under different viewing conditions investigated in Experiment Two. As with the results of Experiment Two, the explanation for this effect lies in the complex set of factors that intervene between visual perception, haptic matching procedures, and strategies utilized by the observers to optimize their success in the face of uncertainty.

No evidence was found with the questionnaire, NF, or FF tests to support the hypothesis that eyestrain resulted from the stimulus conditions tested in Experiment Three.

Experiment Four

Experiment Four was designed to determine whether the influence of camera separation on depth estimation accuracy found in Experiments One and Three would hold for a complex scene in which "strong" cues to depth perception other than retinal disparities were present in the visual imagery. Results from analysis of both dependent measures of depth perception revealed no significant differences for any of the viewing conditions tested -- the same viewing conditions which produced significantly different levels of accuracy of depth estimates in Experiments One and Three. Overall level of depth estimation accuracy for Experiment Four was superior to levels of accuracy found in Experiments One through Three owing to the addition of linear perspective, relative height in field, and interposition cues to depth.

A significant rod depth interval main effect was found for the haptic adjustment measure which took the same general form revealed in analyses of Experiments Two and Three. Overall accuracy for the haptic measure was greater than that found in Experiments One, Two, and Three. This was, of course, an expected difference. Having access to more perceptual information about the spatial layout of a remote scene allows an observer to form more accurate spatial percepts of that scene and to respond more accurately. Thus, it appears that stereo TV neither enhances nor degrades depth perception of scenes which are rich with unambiguous non-disparity cues to depth such as interposition, relative height in the field of view, and linear perspective.

Analysis of eyestrain scale scores revealed no evidence of eyestrain for any of the viewing conditions investigated in Experiment Four. Again, keystoning appears to have produced no eyestrain over the average 19 minute exposure period in which the ratio of camera separation to convergence distance was .125, much larger than the maximum .033 recommended by stereophotographers.

General Conclusions and Implications for Future Research

Depth interval estimation under the stimulus conditions employed in Experiments One, Two, and Three was significantly improved over monoscopic levels when observers were provided with retinal disparity cues to depth. This finding is in accordance with a substantial body of evidence collected under both direct and TV viewing conditions. Thus, the retinal disparities produced by stereo TV displays are not only useful in enabling an observer to detect depth when it exists in the remote environment, they also increase the accuracy of estimates of depth magnitude, though not necessarily in a linear fashion. This is not surprising when one considers everyday experience or the literature of remote manipulation with stereo TV displays, but results presented herein are reflective of more purely perceptual responses than are possible in remote manipulation studies.

Unlike direct viewing conditions in which large, non-fusable disparities can give rise to sensations of depth and enable observers to scale depth intervals more accurately than they can under monocular viewing conditions, it was found that increasing disparities beyond the limits of fusability and into Ogle's area of patent stereopsis resulted in subjective complaints and produced consistently (but not significantly) less accurate depth interval estimates than monoscopic viewing conditions. One obvious implication of this finding for stereo TV applications is that non-fusable images for objects to be compared in depth should be avoided. Apparently, the upper limit of useful disparities with stereo TV displays is somewhat more restricted than the upper limit under direct viewing conditions. It must be pointed out that this statement is made only tentatively on the basis of a single experiment's results and should be replicated. Just what the upper limit is for useful retinal disparities under stereo TV viewing conditions can be determined by replication of Ogle's (1953) original design with televised orthostereoscopic imagery. Whether non-fusable objects which are not of interest in performing a particular task influence the perception of depth between fusable objects is a question which will require further investigation to answer.

Experiment Four was the only experiment involving stereo TV undertaken in NOSC's Teleoperator Performance Laboratory which did not demonstrate a significant advantage for stereo TV viewing conditions relative to monoscopic TV viewing conditions. The reason for this difference in findings can be attributed to the presence of several sources of perceptual information in the remote scene regarding the relative depths of the stimulus rods which was not present in earlier studies. Relative height in the field of view, a pronounced texture gradient, and the interposition of the stimulus rods with the texture gradient provided powerful monocular depth information which increased accuracy overall while washing out the performance advantages found for stereoscopic viewing conditions in earlier studies.

Disparities appear to have merely provided redundant depth information that did not improve performance in situations where monocular depth cues were present in abundance. It is important to perform a more exacting analysis of the stimulus information inherent in natural scenery to determine precisely when retinal disparities do provide useful depth information and when they are redundant to other cues. Such knowledge would allow for design and construction of remote spaces (e.g., high-radiation fuel processing cells) which would not require stereo TV displays for adequate telepresence to perform remote manipulations at tolerable levels of safety and efficiency.

Camera interaxial separation was not found to influence perceived depth in the manner predicted by the geometrical model of depth perception with stereo TV displays. That is, observers were not found to over-estimate or under-estimate objective depth as a direct function of disparity exaggeration ratios. Depth intervals under reduced camera separation conditions appeared flattened, but they also appeared flattened to a lesser degree under orthostereoscopic viewing conditions. According to observers' subjective reports, it was only under viewing conditions in which retinal disparities were exaggerated to three times their normal magnitude by means of camera separation that perceived depth intervals between the rods began to take on their "natural" appearances. These results are in obvious conflict with the geometrical model. They suggest that once observers are practiced and adapted to stereo TV viewing conditions, they interpret the disparity cues present in a scene in light of feedback provided regarding depth scale in that scene. The greater the range of disparities (within fusional limits) corresponding to a given set of depth intervals in the scene, the more accurate observers judgments appear to be. It is now necessary to investigate the course of adaptation within viewing conditions for both experienced and inexperienced stereo TV observers. Also, feedback regarding depth estimation in the remote environment under varying degrees of hyperstereopsis should be investigated.

Alternatives to the geometrical model of depth perception with stereo TV displays must be constructed and tested under controlled conditions. On the basis of experimental results reported herein, these theoretical models will need to incorporate not only disparities, but also the effects of perceptual cues such accommodation, convergence, relative size, textural gradients, interposition, and other higher-order effects such as perceptual adaptation.

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APPENDIX A

INSTRUCTIONS TO OBSERVERS

Verbal Instructions for the Near-Far Test

This is a measure of how quickly you can refocus your eyes from near to far distances. The near and far objects which you will be looking for are small squares which have a gap in one of their sides. This is what the small squares look like. << The experimenter points to the near Landolt square which is illuminated and visible through an aperture 50 cm in front of the observer's eyes >>. Notice that there is another square just like this one at the far end of the room. << The experimenter points to the Landolt square 6 meters distant and asks the observer whether she/he can see it clearly >>. Notice also that gaps in the two squares are on top. When the gaps are in the same position, whether it be up, down, left, or right - they match. Whenever the gaps are in different positions, they do not match.

When we begin testing, you will indicate whether the gaps match or do not match by pressing one of these two buttons. << The experimenter points to the response keypad which rests on a ledge approximately 50 cm in front of the observer >>. Whenever the gaps match you will press the (right/left) button. When they do not match, you will press the (left/right) button.

During actual testing, the room will be totally dark and you will only be able to see the squares when they are lighted. We will take ten measures of refocus time each time you are tested. For the first set of five measures, the near square will light up first and remain lighted for one second before the far square lights up. While the near square is the only square lighted, you should look only at it. Do not redirect your eyes until the far square is lighted. Once the far square is lighted, look for its gap and press the appropriate button on the keypad as quickly as possible, indicating whether or not the near and far squares match.

For the second set of five measures, the far square will light up first and remain lighted for a second before the near square is lighted. Again, do not redirect your eyes to the near square until it is lighted and press the appropriate button as quickly as possible.

The computer will help you. Before each set of five trials, it will tell you which square will be lighted first and which keypad button (left or right) should be pushed to indicate a match. Also, before each measure the computer will say "READY" and there will be a one second delay before the first square is lighted. Once you've pressed the button, the computer will tell you if you were wrong. If the computer says nothing, your response was correct.

All this sounds a bit complicated, but it is really very simple and you will be allowed enough practice to feel comfortable with this test before we begin the actual experiment.

Do you have any questions?

Verbal Instructions for the Flicker Fusion Measure

This is a measure of your ability to detect flickering light. << The experimenter points to the viewing hood depicted in Figure 4. >>. Look into this viewing hood with both eyes open and you will see a flickering red dot of light set within a dark background. Using this hand-held dial, you will adjust the flickering of the light until it no longer appears to be flickering. That is, across the entire area of the dot, you see no flickering at all. This is how that looks. << The experimenter adjusts the flicker rate to the maximum of 50 Hz. >>. Can you see the dot flickering now. << None of the observers answered in the affirmative >>.

We will take four measures of flicker sensitivity each time you are tested. The computer will instruct you. At the beginning of each measure, the computer will say "COUNTER-CLOCKWISE". This is a reminder for you to turn the dial all the way to the stop in the counter-clockwise direction. After you have done so, the flickering should be clearly apparent as it is now << at 25 Hz >> and the computer will say "START". At this point, slowly turn the dial in the clockwise direction until the dot no longer appears to flicker. It is important that you adjust the dial to the point where the flickering just barely disappears. If you overshoot the mark a little, it is OK to turn the dial back in the counter-clockwise direction. When you have adjusted the dial so that the dot no longer flickers, press this button. << The experimenter points out the response button on the side of the dial >>. Be careful not to push this button inadvertently. If you do, inform the experimenter.

Do you have any questions? << The experimenter answers questions. >>

Remember to keep both eyes open and to adjust the dial to the point at which flicker just barely disappears completely.

Verbal Instructions for Stereo and Monoscopic TV

This is a measure of your ability to accurately judge the distances between two rods which you will see on the TV screen in front of you. During the experiment you will wear these special glasses while looking at the screen. << The experimenter hands the observer a pair of polarizer glasses. >> Keep both eyes open at all times and keep your eyes level with the bottom and top of the screen. Rest your chin in the chin cup and do not allow your head to tilt to one side or the other. This will help you to see the rods clearly in depth.

The test consists of sixty trials << ninty-six trials for Experiments Three and Four >>. At the beginning of each trial the screen will go blank and you will not be able to see the rods. Next, the computer will announce the trial number and two vertical rods will appear on the screen. Your task will be to describe the distance between the two rods in depth. << Experimenter demonstrates the depth dimension to the observer with his hands and insures that she/he understands that it is the depth interval between rods which is to be measured. >> First, the computer will ask the question, "LEFT OR RIGHT?". Look at the rods carefully and decide whether the left rod or the right rod appears to be closer to you, then speak your answer out loud. The computer will immediately tell you whether you were correct or wrong. Next, the computer will ask, "HOW FAR?". Look at the rods carefully again and decide how many inches they appear to be separated in depth, then speak your answer. It is OK to use fractional numbers when making your reply. For example, three and one-half inches is an acceptable reply.

Notice that on the shelf top in front of you there are two pegs. The peg on the left is attached to a sliding device which can be moved in and out in depth. The right peg does not move and has a cushion grip with a red pushbutton on top of it. You will use the distance between these two pegs to indicate the distance that the rods appear to be separated in the televised scene. When the computer says "SLIDER", move the left peg to a distance from the right peg that is equivalent to the distance the two rods are separated in depth. When you have done so, press the button on top of the right peg. The computer will immediately tell you how accurately you positioned the peg. For example, if the rods were separated by seven inches and you separated the pegs by five inches before pushing the button, the computer will say "SHORT TWO POINT ZERO". If the rods were separated by two inches and you moved the pegs two and one-half inches apart, the computer will say "LONG POINT FIVE". The rods may be separated from zero to twelve inches in depth. Moving the pegs to a side-by-side position like this will indicate that the two rods appear to have no depth between them. Notice that moving the left peg all the way back into the near stop does not set it equal in depth with the right peg, so do not pull the left peg back into the stop when the rods do not appear to be separated in depth.

Do your best, but do not be overly concerned with your accuracy at first You will be allowed enough practice to feel comfortable with this test before we begin the actual experiment.

Do you have any questions?

APPENDIX B

Hardware Calibration Procedures

Prior to each day's experimental testing, the following set of calibration procedures were carried out on the video equipment:

1) Cameras and monitors were turned on and allowed to warm up for at least 15 minutes.

2) Camera lenses were adjusted to pre-selected magnification values (i.e., 1X, 2X, or 3X) and focused for the distance of the camera convergence point. Lens aperture was checked to insure an f-stop setting of 5.6.

3) Cameras were separated and converged to pre-selected distances. This also involved centering the camera baseline with respect to the lateral midpoint between the two stimulus rods. Cameras were thus symmetrically converged regardless of camera separation.

4) Brightness and contrast of displayed targets were matched between the left and right video channels by the use of opaque masks with holes cut out to reveal a segment of one of the rods. With both rods displayed on both channels, masks were placed in front of the left and right channel monitors and adjustments were made to brightness and contrast knobs on the front of the monitors.

Prior to testing each experimental observer, an additional procedure was performed to finely align the cameras. An opaque, star-shaped target was positioned at the convergence point of the cameras and used as test pattern for finely adjusting the tilt and roll of the cameras such that screen images of the star were precisely aligned. Following a testing session, the star was repositioned at the convergence point to determine whether cameras had drifted out of alignment during testing.

APPENDIX C

Text of the Computer-Administered Preliminary Mood and Eyestrain Questionnaire

NOTE: Screen frames 12 through 16 were excluded from the concluding version of this questionnaire.

SCREEN FRAME 1

```
==========================================
INDICATE HOW YOU FEEL RIGHT NOW
BY ENTERING THE APPROPRIATE NUMBER
FOR EACH OF THE SCALES BELOW

TIRED  : 1 : 2 : 3 : 4 : 5 :  ALERT

YOUR RESPONSE? =>

==========================================
```

SCREEN FRAME 2

```
==========================================
INDICATE HOW YOU FEEL RIGHT NOW
BY ENTERING THE APPROPRIATE NUMBER
FOR EACH OF THE SCALES BELOW

RELAXED  : 1 : 2 : 3 : 4 : 5 :  TENSE

YOUR RESPONSE? =>

==========================================
```

SCREEN FRAME 3

```
==========================================
INDICATE HOW YOU FEEL RIGHT NOW
BY ENTERING THE APPROPRIATE NUMBER
FOR EACH OF THE SCALES BELOW

DISTRACTED  : 1 : 2 : 3 : 4 : 5 :  FOCUSED

YOUR RESPONSE? =>

==========================================
```

SCREEN FRAME 4

```
==========================================
    INDICATE HOW YOU FEEL RIGHT NOW
   BY ENTERING THE APPROPRIATE NUMBER
      FOR EACH OF THE SCALES BELOW

 DEPRESSED  : 1 : 2 : 3 : 4 : 5 :  ELATED

           YOUR RESPONSE? =>

==========================================
```

SCREEN FRAME 5

```
==========================================
    INDICATE HOW YOU FEEL RIGHT NOW
   BY ENTERING THE APPROPRIATE NUMBER
      FOR EACH OF THE SCALES BELOW

ENTHUSIASTIC  : 1 : 2 : 3 : 4 : 5 :  BORED

           YOUR RESPONSE? =>

==========================================
```

SCREEN FRAME 6

```
==========================================
    INDICATE HOW YOU FEEL RIGHT NOW
   BY ENTERING THE APPROPRIATE NUMBER
      FOR EACH OF THE SCALES BELOW

                EYESTRAIN
NOT AT ALL  : 1 : 2 : 3 : 4 : 5 :  VERY MUCH

           YOUR RESPONSE? =>

==========================================
```

SCREEN FRAME 7

==

INDICATE HOW YOU FEEL RIGHT NOW
BY ENTERING THE APPROPRIATE NUMBER
FOR EACH OF THE SCALES BELOW

EYE PAIN
VERY MUCH : 1 : 2 : 3 : 4 : 5 : NOT AT ALL

YOUR RESPONSE? =>

==

SCREEN FRAME 8

==

INDICATE HOW YOU FEEL RIGHT NOW
BY ENTERING THE APPROPRIATE NUMBER
FOR EACH OF THE SCALES BELOW

HEADACHE
NOT AT ALL : 1 : 2 : 3 : 4 : 5 : VERY MUCH

YOUR RESPONSE? =>

==

SCREEN FRAME 9

==

INDICATE HOW YOU FEEL RIGHT NOW
BY ENTERING THE APPROPRIATE NUMBER
FOR EACH OF THE SCALES BELOW

PAIN IN THE NECK OR SHOULDERS
VERY MUCH : 1 : 2 : 3 : 4 : 5 : NOT AT ALL

YOUR RESPONSE? =>

==

SCREEN FRAME 10

==

INDICATE HOW YOU FEEL RIGHT NOW
BY ENTERING THE APPROPRIATE NUMBER
FOR EACH OF THE SCALES BELOW

PAIN IN THE ARMS OR LEGS
NOT AT ALL : 1 : 2 : 3 : 4 : 5 : VERY MUCH

YOUR RESPONSE? =>

==

SCREEN FRAME 11

==

INDICATE HOW YOU FEEL RIGHT NOW
BY ENTERING THE APPROPRIATE NUMBER
FOR EACH OF THE SCALES BELOW

BLURRED VISION
VERY MUCH : 1 : 2 : 3 : 4 : 5 : NOT AT ALL

YOUR RESPONSE? =>

==

SCREEN FRAME 12

==

APPROXIMATELY HOW MANY HOURS OF SLEEP
DID YOU GET LAST NIGHT?
EXAMPLE: 8.5

YOUR RESPONSE? =>

==

SCREEN FRAME 13

==

DO YOU FEEL WELL-RESTED? (Y/N)
YOUR RESPONSE? =>
WHY NOT? =>

==

SCREEN FRAME 14

==

IS THERE ANYTHING UNUSUAL ABOUT
YOUR VISION TODAY? (Y/N) =>

WHAT? =>

==

SCREEN FRAME 15

==

HAD ANY COFFEE IN THE PAST
TWO HOURS? (Y/N) =>

HOW MANY CUPS? =>

==

SCREEN FRAME 16

==

SMOKED ANY CIGARETTES IN THE PAST
TWO HOURS? =>

HOW MANY AND OF WHAT BRANDS? =>

==

APPENDIX D

Table 30.
Randomized Orders for Depth Intervals (In Inches)
Used in Stereo TV Testing Sessions

Trial	Order 1	Order 2	Order 3	Order 4
1	6	6	8	6
2	4	8	10	0
3	2	4	0	10
4	6	2	4	0
5	10	0	2	2
6	0	2	8	4
7	4	4	6	8
8	2	0	2	10
9	10	10	0	8
10	0	6	4	6
11	8	8	10	4
12	8	10	6	2
13	6	8	2	8
14	4	2	8	8
15	8	6	10	6
16	8	8	4	2
17	4	4	8	0
18	6	4	4	2
19	0	10	0	10
20	10	10	10	4
21	0	0	0	0
22	2	6	6	10
23	2	2	2	4
24	10	0	6	6
25	8	10	10	6
26	4	0	0	0
27	8	2	4	8
28	6	6	8	2
29	6	10	8	0
30	10	0	10	10
31	2	6	6	4
32	0	4	0	2
33	0	8	2	10
34	2	4	4	4
35	10	2	6	6
36	4	8	2	8
37	8	10	0	8
38	4	10	2	6
39	8	8	4	6
40	6	6	10	0
41	4	4	8	10
42	0	4	8	2
43	10	8	0	8
44	0	0	2	4
45	2	2	4	4
46	2	6	6	10

Table 30. Randomized Orders for Depth Intervals (Inches) Used in Stereo TV Testing Sessions (Continued)

Trial	Order 1	Order 2	Order 3	Order 4
47	6	2	10	0
48	10	0	6	2
49	2	6	10	2
50	4	0	4	6
51	6	0	4	0
52	10	8	8	4
53	0	6	8	8
54	8	10	10	6
55	8	2	2	10
56	4	8	2	4
57	10	4	6	2
58	2	4	0	0
59	0	10	6	10
60	6	2	0	8
61	8	2	6	10
62	0	8	8	2
63	4	8	6	8
64	2	2	0	10
65	0	10	2	4
66	4	10	4	0
67	6	4	8	6
68	6	4	10	4
69	2	0	0	0
70	10	0	2	2
71	8	6	4	8
72	10	6	10	6
73	0	2	2	10
74	4	0	10	6
75	2	8	2	4
76	10	2	6	0
77	6	10	10	4
78	8	6	6	0
79	4	4	4	2
80	10	10	0	6
81	8	4	8	10
82	2	8	4	8
83	6	0	0	8
84	0	6	8	2
85	6	8	2	6
86	8	10	6	4
87	2	4	0	4
88	0	8	6	2
89	10	2	10	0
90	4	6	4	10
91	4	2	4	8
92	10	6	10	10
93	2	0	8	2
94	0	4	2	8
95	6	10	8	6
96	8	0	0	0

Table 31 .
Randomized Orders of Landolt Square Gap Orientations
for the Near-Far Test

Where: L = Left R = Right U = Up D = Down

Order 1

Trial	Gap Orientation		Match
Near First	Near Target	Far Target	
1	L	L	Y
2	U	D	N
3	D	D	Y
4	R	R	Y
5	L	R	N
Far First	Far Target	Near Target	
6	D	U	N
7	L	L	Y
8	R	L	N
9	U	U	Y
10	L	R	N

Order 2

Trial	Gap Orientation		Match
Near First	Near Target	Far Target	
1	D	D	Y
2	R	R	Y
3	U	D	N
4	L	R	N
5	L	L	Y
Far First	Far Target	Near Target	
6	R	L	N
7	L	L	Y
8	D	U	N
9	L	R	N
10	U	U	Y

==

Order 3

Trial	Gap Orientation		Match
Near First	Near Target	Far Target	
1	D	U	N
2	L	L	Y
3	R	L	N
4	U	U	Y
5	L	R	N
Far First	Far Target	Near Target	
6	L	L	Y
7	U	D	N
8	D	D	Y
9	R	R	Y
10	L	R	N

Order 4

Trial	Gap Orientation		Match
Near First	Near Target	Far Target	
1	R	L	N
2	L	L	Y
3	D	U	N
4	L	R	N
5	U	U	Y
Far First	Far Target	Near Target	
6	D	D	Y
7	R	R	Y
8	U	D	N
9	L	R	N
10	L	L	Y

Table 32.
Randomized Orders of In-Phase and Counter-Phase Flicker for the Flicker Fusion Threshold (CFF) Measure

Where: IP = In-Phase Flicker CP = Counter-Phase Flicker

Trial	Order 1	Order 2	Order 3	Order 4
1	IP	CP	IP	CP
2	CP	IP	IP	CP
3	IP	CP	CP	IP
4	CP	IP	CP	IP

Table 33.
Randomized Order of Testing Sessions for Experiment One.

Viewing Condition	Magnification
19.05 Cm Camera Separation	3X (5.9° H. FOV)
3.175 Cm Camera Separation	3X
3.175 Cm Camera Separation	1X (17.8° H. FOV)
Monoscopic TV	2X (11.9° H. FOV)
6.350 Cm Camera Separation	1X
Monoscopic TV	1X
3.175 Cm Camera Separation	2X
19.05 Cm Camera Separation	2X
Monoscopic TV	3X
Binocular Direct View	---
6.350 Cm Camera Separation	3X
6.350 Cm Camera Separation	2X
19.05 Cm Camera Separation	1X

Table 34.
Randomized Order of Testing Sessions for Experiment Two.

Viewing Condition
Binocular Direct View
Cameras Converged at Middle of Workspace
Camera Axes Paralleled
Cameras Converged 20 Cm in Front of Workspace
Monoscopic TV

Table 35.
Randomized Order of Testing Sessions
for Experiment Three.

Viewing Condition
3.175 Cm Camera Separation
19.05 Cm Camera Separation
Monoscopic TV
6.350 Cm Camera Separation
Binocular Direct View

Table 36.
Randomized Order of Testing Sessions
for Experiment Four.

Viewing Condition
Monoscopic TV
6.350 Cm Camera Separation
3.175 Cm Camera Separation
19.05 Cm Camera Separation
Binocular Direct View

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